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EVALUATING THE USE OF GRANULAR ACTIVATED CARBON AT PASSAIC VALLEY, NEW JERSEY

by

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Passaic Valley Water Commission
Clifton, New Jersey 07015

Contract No. CI-76-0138

Project Officer

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Drinking Water Research Division
Water Engineering Research Laboratory
Cincinnati, Ohio 45268

This study was conducted
in cooperation with the
Little Falls Filtration Plant
Totowa, New Jersey 07511

WATER ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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16. ABSTRACT An 11,500 m^3/day (3MGD) side stream of treated Passaic River water was routed to three pressure vessels in parallel, each containing a different commercial brand of granular activated carbon. For 13 weeks the virgin adsorbents were monitored for the following parameters: organic carbon, organic halogens, and thirty-six specific organic compounds. The adsorbents were regenerated on-site using an electric (infrared) tunnel furnace (45 kg/hr) and following regeneration, returned to service. This cycle was repeated three times. The efficiency of regeneration depended on the parameter used as the index of restoration. The iodine numbers, apparent densities, and effective sizes were virtually unchanged. The ash content increased while the capacity for removing free chlorine decreased upon regeneration. The ash content increase was probably the result of chloride and sulfide build-up. The capacity for removing total organic halogen was restored to about 50 % of its original (virgin) capacity. The capacity for removing total orgainc carbon also decreased after the first regeneration, but then increased following the second and third regeneration. The pore volume and pore area were measured after the second regeneration, and both declined. Fluorometric and ultraviolet absorbance measurements did not prove to be useful surrogates for monitoring either regeneration or performance. The total cost of regeneration, excluding amortized furnace and appurtenances costs, was approximately $0.50/Kg (20 to 25¢/1b) of activated carbon.

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Sunstances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

Trace organics are present in drinking water sources and certain halogenated compounds are produced during the chlorination step in water treatment. This publication examines the results of research to minimize the concentration of these organics by adsorption on granular activated carbon and on-site reactivation using an electric furnace.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

A project was undertaken at the Little Falls Filtration Plant in Totowa, New Jersey, to study the effectiveness and cost of using granular activated carbon for removing organic compounds from drinking water. In 1978, an 11,500-m^3/day (3 MGD) side stream of finished drinking water (i.e. after coagulation, settling, filtration, and chlorination) was routed to three pressure vessels in parallel, each containing a different commercial brand of granular activated carbon. For several weeks, the virgin adsorbents were monitored for the following parameters: organic carbon, organic halogens, and 36 specific organic compounds. The adsorbents were regenerated onsite with an electric (infrared) tunnel furnace (45 kg/hr) and returned to service following regeneration. This cycle was repeated three times.

The efficiency of regeneration depended on the parameter used as the index of restoration. The iodine numbers, apparent densities, and effective sizes were virtually unchanged. The ash content, on the other hand, increased, whereas the capacity for removing free chlorine decreased upon regeneration. In addition to carbon being lost to carbon monoxide and carbon dioxide, and thus some residual ash, the ash content increase probably resulted from a build-up of chlorides, with perhaps some sulfur-containing compound such as sodium sulfite, the compound used to dechlorinate within the Little Falls plant. The capacity for removing total organic halogen was restored to about 50 percent of its original (virgin) capacity. The capacity for removing total organic carbon also decreased after the first regeneration, but then increased following the second and third regeneration. The pore volume and pore area were measured after the second regeneration, and both declined. Fluorometric and ultraviolet absorbance measurements did not prove to be particularly useful surrogates for monitoring either regeneration or performance. The total cost of regeneration, excluding amortized costs of furnace and appurtenances, was approximately $0.50/kg (20¢ to 25¢/lb) of activated carbon.

This report was submitted fulfillment of Contract No. CI-76-0138 by the Passaic Valley Water Commission under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from March 1978 to October 1981.

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SECTION 1

INTRODUCTION

The Passaic River, the source of water for the Little Falls Filtration Plant, has a history of organic contamination (1). Because the River represents a major source of water in northern New Jersey, Hunter and Sabitino (2) conducted an intensive sampling program to locate sources of halogenated hydrocarbons and halogenated pesticides on the watershed. Their study showed chloroform was the predominant organic contaminant identified in the water during the summer months, yet when ice covered the river and its tributaries, methylene chloride predominated. Trace concentrations of industrial solvents and certain pesticides were occasionally detected, indicating intermittent discharges upstream.

In the early 1970's, a study (3) was conducted by the Passaic Valley Water Commission to upgrade the Little Falls facility, and granular activated carbon adsorption was investigated for controlling trace organics. In that early work, the two general parameters used to assess adsorption performance were total organic carbon (TOC) and the carbon chloroform extract (CCE). That study produced useful information but left many questions unresolved as to the effectiveness of activated carbon for removing specific organic compounds.

By the mid-1970's, giant strides had been made in identifying trace quantities of organic chemicals in water. In addition, advances were being made in furnace technology for regenerating activated carbon, so a follow-up study at the Little Falls Filtration Plant was designed to incorporate new analytical techniques and determine the effectiveness and cost of using granular activated carbon with on-site regeneration. The specific objectives of this new project were to:

(1) Study the use of granular activated carbon in a post-filtration mode through two or more regeneration cycles, emphasizing the changes in organic quality of the finished water.

(2) Investigate on-site an electric furnace for regenerating the activated carbon.

(3) Determine the cost of regenerating the activated carbon.

SECTION 2

CONCLUSIONS

1. An empty bed contact time of 8 minutes is inadequate for more than a few weeks of service for removing TOC and TOX in the Little Falls Water Treatment Plant.

2. The indices commonly used to govern furnace operating conditions (e.g., iodine number, apparent density, effective size, and ash content) are not useful surrogates relative to TOC and TOX removal capacity on regenerated activated carbon receiving treated Passaic River water.

3. If granular activated carbon adsorption is to be used in the Little Falls Water Treatment Plant, the current chlorination/dechlorination practice (which allows variable and sometimes high concentrations of free chlorine to be applied to the adsorbent) should be closely examined and perhaps replaced with an alternative disinfection scheme.

SECTION 3

DESCRIPTION OF FACILITY AND EXPERIMENTAL METHODS

Water Treatment Plant

The Little Falls Filtration Plant, owned and operated by the Passaic Valley Water Commission, is located on the Passaic River in Totowa, New Jersey. The Passaic Valley Water Commission is entitled to 283,900 m^3/day (75 million gallons of water per day, MGD) from the Passaic River which enters the filtration plant through a diversion channel. The average flow through the plant is 208,000 m^3/day (55 MGD) and excess water is used to generate hydroelectric power.

Treatment consists of prechlorination, alum coagulation, settling, filtration (anthracite coal over sand), and at times dechlorination with sodium sulfite. Powdered activated carbon, cationic polymers, and caustic can also be dosed when necessary. The original facility was built in 1902 and was the first water treatment plant in the United States to utilize George Fuller's rapid sand filter design. In 1966, the plant expanded its production capacity from 182,000 m^3/day (48 MGD) to 364,000 m^3/day (96 MGD). A schematic flow diagram of the water treatment plant is shown in Figure 1.

The organic quality of the Passaic River is variable because an estimated 92 municipal and 9 industrial waste water facilities discharge approximately 216,000 m^3/day (57 MGD) into the river above the Little Falls Filtration Plant intake. For perspective, the contribution from waste water in the river ranges from one percent or less during high flows to as much as 68 percent during low river flow periods. In addition to the river source, the Passaic Valley Water Commission is entitled to approximately 156,000 m^3/day (41 MGD) of chlorinated water from the Wanaque Reservoir. This water is passed through pressure sand filters at the Little Falls Filtration Plant before being blended with the treated river water (Figure 1).

For this adsorption study, three of the Wanaque pressure filters were taken out-of-service and refurbished. The sand and gravel were removed and the interiors sand blasted. A one-mil thick epoxy coating was applied to the inside wall of each tank and allowed several days to cure. Stainless steel plates were installed in the bottom of the vessels to support the absorbent. These pressure filters are 7.5 m long and 2.5 m in diameter, and were filled with approximately 7 m^3 of granular activated carbon. Three brands of activated carbon were used in the study (one type in each

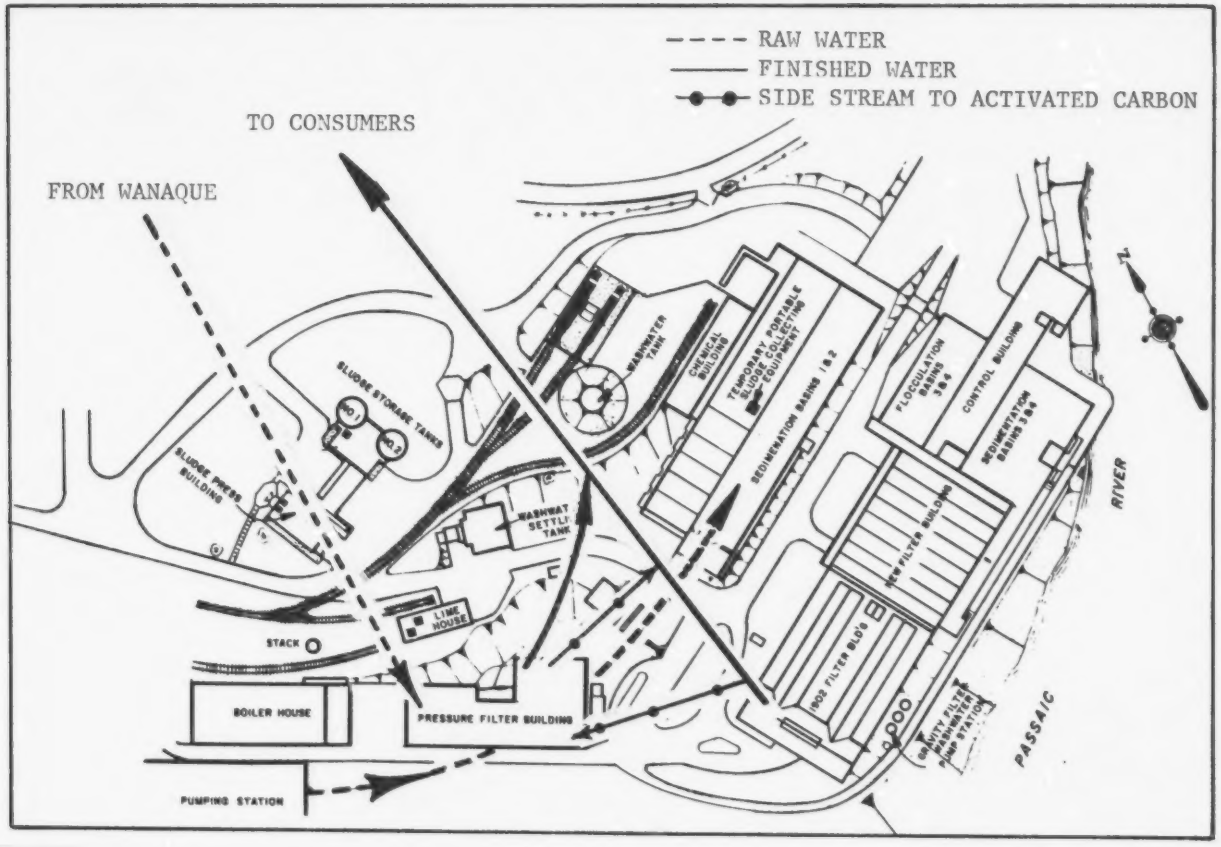

Figure 1. Little Falls, New Jersey Filtration Plant

vessel). The properties and quantities are shown in Table 1. With approximately 1 m of adsorbent, and a hydraulic loading of 1800 L/min, the empty bed contact time was about 8 minutes.

Treated water from the Little Falls Filtration Plant was routed to these adsorbers and the activated carbon exposed (without being backwashed) for several weeks, then regenerated and put back into service. The exposure/regeneration cycles were as follows:

Virgin Adsorbent - March 15, 1978 - June 2, 1978
Once Regenerated - Sept. 12, 1978 - Jan. 2, 1979
Twice Regenerated - April 12, 1979 -Sept. 4, 1979
Thrice Regenerated - April 8, 1980 - July 1980

TABLE 1. PROPERTIES OF GRANULAR ACTIVATED CARBON

Product Name	Filtrasorb® F-400	Hydrodarco® HD-1030	Nuchar® WV-W
Manufacturer	Calgon Corp. Pittsburg, PA	ICI Americas Inc. Wilmington, DE	Westvaco Covington, VA
Base Material	Bituminous Coal	Lignite	Bituminous Coal
U.S. Standard Sieve Size	12 x 40	10 x 30	12 x 40
Effective Size, mm	0.7	0.8	0.7
Uniformity Coefficient	< 1.9	< 1.7	< 1.8
Apparent (or vibrating feed) density, g/cc	0.47	0.43	0.57
Washed density, lb/ft^3	25	23.5	32-38
Iodine Number, mg/g	1023	600	850
Surface Area, m^2/g	1050	650	1100
Available in:	60 lb. bags; bulk	40 lb. bags; bulk	40 lb. bags; one ton box; bulk
Quantity per adsorber lb (kg)	14,220 (6,460)	13,600 (6,180)	18,200 (8,272)

Regeneration Process

Exhausted activated carbon was educted to a storage vessel and from there, fed to the furnace by a dewatering screw. An infrared tunnel furnace* was selected for this research project for two reasons:

*Shirco, Inc., Dallas, TX

1. Some water utilities in the United States have limited fossil fuels available yet adequate electric power. Some of this power may be hydroelectrically generated at the water works.

2. An electric furnace may be started or shut down without long warm-up or cool-down periods.

Further, a tunnel furnace conveys the adsorbent on a traveling belt and this gentle handling was speculated to reduce mechanical attrition losses during the regeneration process. The design characteristics for the furnace are given in Table 2 and a schematic is shown in Figure 2. A fifty percent mixture of water and exhausted activated carbon is fed into the unit through a rotary air lock then dropped onto a wire-woven conveyor belt. As it passes through the furnace, the activated carbon is leveled to a depth of about 2.5 cm (one inch) and heated by infrared radiation in various temperature zones. Note, the activated carbon is not mechanically agitated as it passes through the furnace.

TABLE 2. ELECTRIC FURNACE, LITTLE FALLS FILTRATION PLANT

Dimensions	4 feet (width) x 20 feet (length) (1.2 m x 6 m)
Activated Carbon residency time	20 to 25 minutes
Temperature	
drying zone	1150°F (620°C)
activation zone	1650°F (900°C)
Power Required	100 kW
Warm-up time	30 minutes
Weight	17,000 lbs (7727 kg)
Regeneration Capacity	100 lb/hr (45 kg/hr)

In the first zone, where temperatures range from 200°C - 315°C (400°F - 600°F) residual water is boiled off. The steam generated in this drying zone provides the regeneration atmosphere in the latter stages of the process. In the second zone, the temperature is increased to approximately 540°C (1000°F) to drive off volatile compounds and char the high molecular weight organics. This organic char is burned off in the third zone at a temperature of approximately 875°C (1600°F). Exhaust gasses are passed through a wet scrubber (no afterburner) and the regenerated adsorbent is discharged into a quench tank and cooled before being transported back to the adsorber.

Experimental Methods

The parameters measured, the frequency of monitoring, and the analytical methods used to evaluate adsorption and regneration performance are shown in Table 3. Appendix A present details on the specific organic analyses. This evaluation was truely a team effort as it involved the utility, its engineering consultant, a local university, and the furnace manufacturer. Each phase of the study will be described.

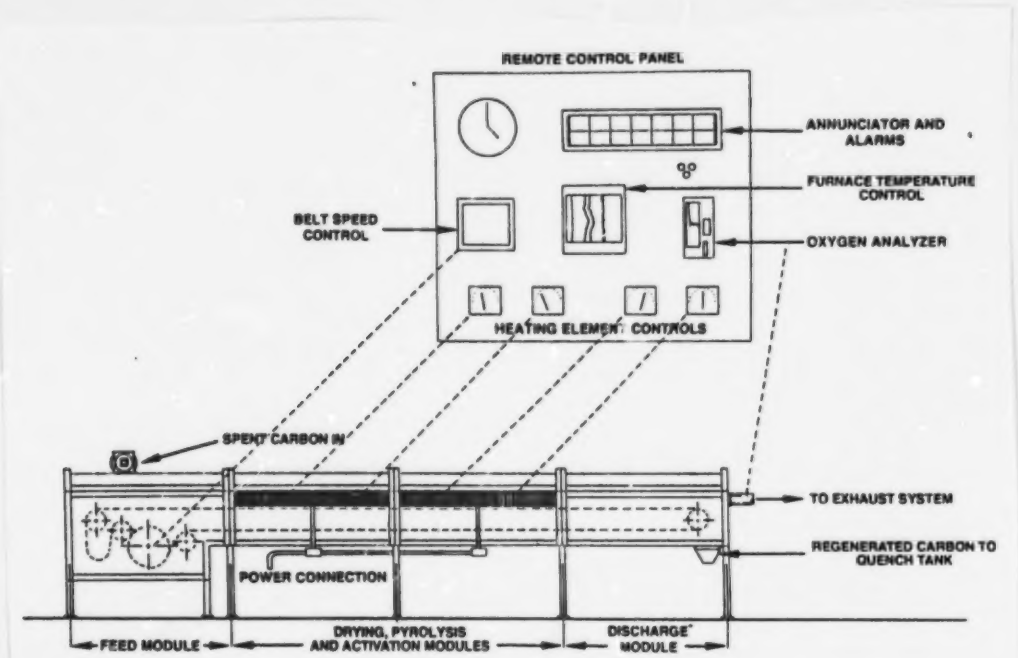

Figure 2. Cross Section of Infra-red Tunnel Furnace

TABLE 3. PERFORMANCE MONITORS

Parameter	Frequency	Procedure or Condition	Analyzed by
Total organic carbon (TOC)	Weekly	Ultra-low TOC Dohrmann DC-54 (4)	Little Falls Filtration Plant personnel
UV absorbance	Weekly	254 nm (5)	
Fluorescence (RFM)	Weekly	Excitation @ 340 nm, emission @ 390 nm (6) reported as RFM (Rapid Fluorometric Method)	
Bacteriological	Weekly	Standard Plant Count @ 35°C, Coliform analysis (7)	
Color, odor, turbidity, pH temperature, iron, manganese chlorine residual	Weekly		
Total organic halogen (TOX)	Performed weekly on water; before and after regeneration on the adsorbent	Pyrolysis, microcoulometric detector (8-10)	Havens & Emerson, Saddlebrook, NJ
Apparent density, iodine number, phenol number	Before and after regeneration on the adsorbents	(11)	Havens & Emerson and Shirco, Inc., Dallas, TX
Specific organics See A below	Weekly	Extraction with n-pentane, capillary column gc with electron capture detector	Rutgers University New Brunswick, NJ
See B below	Weekly	Steam distillation, packed column gc, electron capture detector	

A. methylene chloride; chloroform; 1,2-dichloroethane; 1,1,1-trichloroethane; carbon tetrachloride; trichloroethylene; bromodichloromethane; dibromochloromethane; 1,2-dibromethane; tetrachloroethylene; bromoform; tetrachloroethane; diiodomethane; 1,2-, 1,3-, and 1,4-dichlorobenzene; 1,2,4-trichlorobenzene; fluoroform; chloromethane; bromomethane; vinyl chloride

B. Polychlorinated biphenyls; γ-BHC; lindane; aldrin; dieldrin; heptachlor; heptachlor epoxide; toxephene; o,p'-DDE; o,p'-DDT, p,p'-DDD, o,p-DDT; methyoxychlor; mirex, endrin, chlordane

SECTION 4

PERFORMANCE OF VIRGIN AND REGENERATED ACTIVATED CARBON

Virgin Activated Carbon

The refurbished pressure filters were charged with granular activated carbon, backwashed, and put into service as adsorption vessels on March 14, 1978. Chlorinated treated water from the Little Falls Filtration Plant was passed continuously through the adsorbers for 13 weeks at approximately 1800 L/min (480 gpm). Because of analytical problems, routine monitoring of most of the specific organic compounds listed in Table 3 was delayed until the last 4 or 5 weeks in this first adsorption cycle. Little definitive data, therefore, were gathered on the behavior of specific organic compounds other than trihalomethanes with virgin activated carbon. Note, in Table 4, the alarmingly high concentrations of one polychlorinated biphenyl, arachlor 1254, in the influent. By sampling upstream in the Passaic River, the source of this PCB was discovered and the discharge stopped. This arachlor was not effectively removed by the activated carbon. Of the three dozen specific organics monitored for (Table 3), less than 20 compounds were detected (Table 4).

Figure 3 illustrates the total trihalomethane (THM) concentrations in the influent to the activated carbon and the cummulative THM removal per unit weight of activated carbon. Recall from Table 1, because of density differences, different quantities of activated carbon were used in each adsorber, however, the loading curve in Figure 3 is an average of all three types of activated carbon. The THM concentration in the Passaic River was generally less than 1 microgram per liter (ug/L) but ranged from 40 to 165 ug/L after chlorination and conventional treatment. Chloroform is the predominant THM. The concentration of THMs in the effluent from the activated carbon exceeded 100 ug/L between the eighth and ninth week. The adsorption capacity for trihalomethanes on the virgin adsorbents ranged from 0.5 to 1 mg THM/g activated carbon.

The total organic carbon (TOC) concentrations in the influent to the virgin activated carbon ranged from 1.5 milligrams per liter (mg/L) to 3.9 mg/L with a mean of 2.7 mg/L. By looking at the average effluent/influent TOC ratios, Figure 4, one notes that after about 60 days the ratio levels off to approximately 70 percent. This "plateau phenomena" or steady state removal is typical of TOC adsorption on granular activated carbon and has been explained as either biological degradation (12) or "slow adsorbing compounds" (13). The effluent/influent TOC ratio stayed at this plateau for the duration of the run despite influent fluctations of TOC.

TABLE 4. EFFECTIVENSS OF TREATMENT FOR SPECIFIC ORGANIC COMPOUNDS DURING VIRGIN ADSORPTION CYCLE*

Organic Compounds	Passaic River	After Conventional Treatment, Before Adsorption	After Adsorption		
			HD-1030	WV-W	F-400
α-benzene hexachloride, ng/L	<0.01	ND	ND	ND	ND
β-benzene hexachloride, ng/L	0.1-87 (21.6)	0.02-61 (12)	ND	ND	ND
Carbon tetrachloride, ug/L	ND-0.2 (0.1)	ND-0.3 (0.2)	0.1-0.3 (0.2)	<0.1-0.4 (0.2)	<0.1-0.3 (0.2)
Dieldrin, ng/L	ND-<0.1 (0.1)	ND-<0.1 (<0.1)	ND	ND	ND
diiodomethane, ug/L	<0.3	<0.3-1.4 (0.8)	<0.3	<0.3	<0.3
heptachlor epoxide, ng/L	ND-21 (11.8)	0.01-22.0 (9.0)	ND-10 (1.2)	ND-10 (1.2)	ND-10 (2.2)
Heptachlor, ng/L	ND-39 (20.7)	ND-0.1 (<0.1)	<0.1	ND	ND
PCB (arochlor 1254) ug/L	0.4-346.0† (175)	ND-166 (74)	ND-163 (80)	ND-216 (84)	ND-116 (29)
p-dichlorobenzene, ug/L	ND-<1 (<1)	<1-4 (<1)	ND-<1 (<1)	ND-<1 (<1)	ND-1 (<1)
tetrachloroethylene, ug/L	ND-1.3 (0.5)	ND-1.2 (0.6)	<0.1-0.9 (0.3)	<0/1-0.9 (0.3)	<01.-0.9 (0.3)
2,2-tetrachloroethane, ug/L	ND-1.3 (<0.3)	<0.3-1-3 (<0.3)	<0.3	<0.3	<0.3
1,1,1-trichloroethane, ug/L	ND-4.3 (2.4)	ND-6.6 (2.8)	0.7-6.4 (2.8)	0.7-10-10.1 (3.0)	0.8-4.9 (3.1)
trich)oroethylene, ug/L	ND-1.8 (1.0)	ND-1.4 (0.7)	ND-0.4 (0.2)	0.1-0.4 (0.3)	0.1-0.5 (0.3)
1,2,4-trichlorobenzene, ug/L	<2	<2	<2	<2	<2
O,p-DDE, ng/L	<0.01	<0.01	<0.01	<0.01	<0.01
O,p-DDT, ng/L	<0.01	ND	ND	ND	ND
O,p-DDD, ng/L	<0.01	ND	ND	ND	ND

*These analyses were only run during the last 4 weeks of the 13 week long test.
ND = none detected
( ) = average concentration
†See text for explanation of these concentrations.

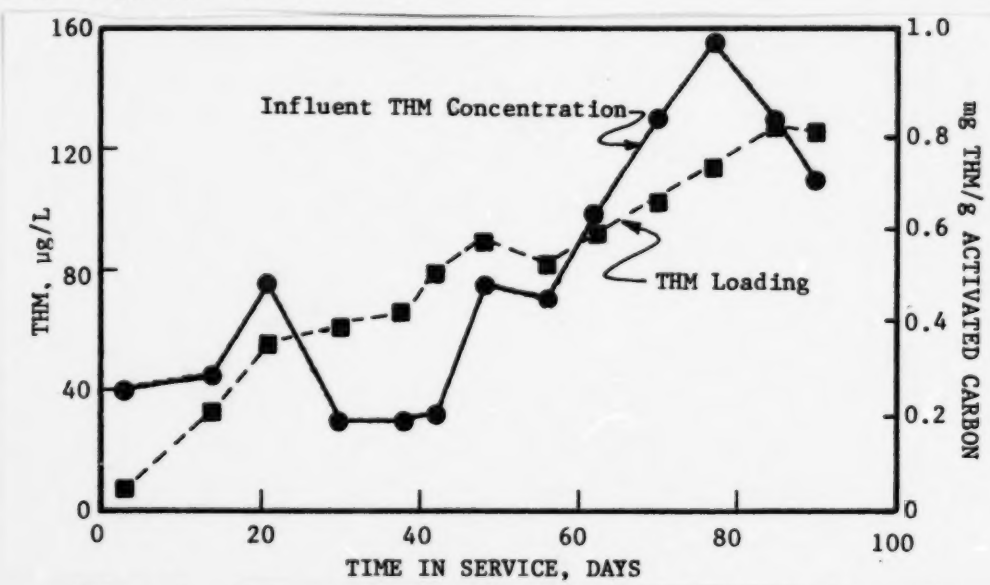

Figure 3. Average Trihalomethane Influent Concentrations and Loading on Virgin Activated Carbon

Organic halogen (TOX) concentrations were measured on both the water and the adsorbent. For the latter, a core sampler was used to collect activated carbon from the top and bottom of each adsorber. The TOX concentrations in the influent water to the activated carbon ranged from 87 ug/L to 320 ug/L. The TOX behaved much like the TOC in that removal was consistent until approximately the 9th week, then a plateau developed (Figure 4). For the remaining weeks in the study, TOX removal was about 45 percent despite fluctuations in the influent TOX concentrations. Figure 5 illustrates the empirical loading (averaged top and bottom TOX concentrations) on the activated carbon. The calculated TOX loadings (3.8 mg/g) based on influent and effluent concentrations are very close the loadings actually observed (3.3 mg/g).

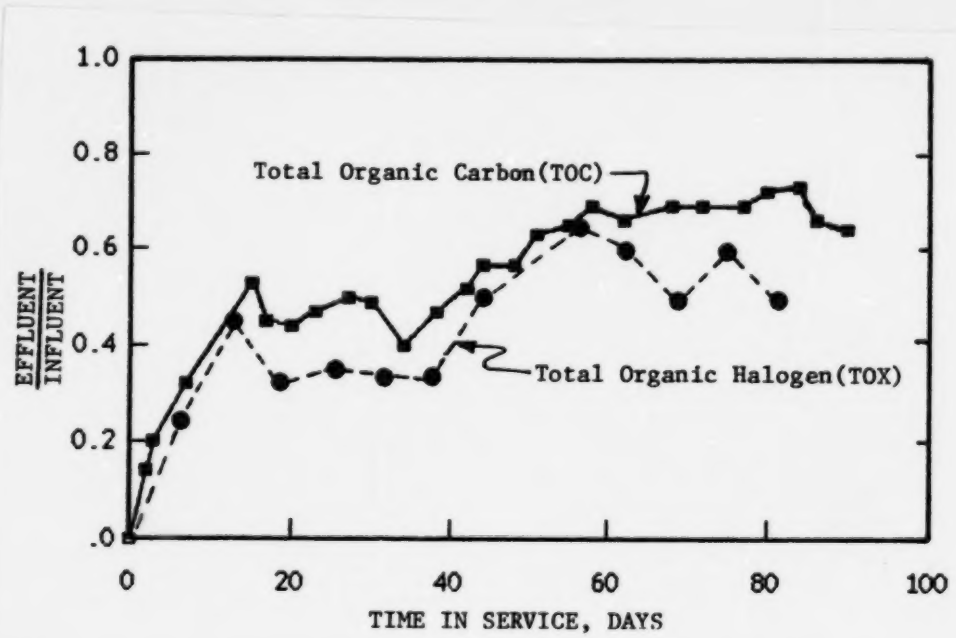

Figure 4. Removal of Total Organic Carbon and Total Organic Halogen with Virgin Activated Carbon

First Regeneration

The length of the virgin adsorption cycle was arbitrarily set at 3 months. The adsorbents were then sequentially educted into a storage bin, fed into the furnace, quenched, then returned to the adsorbers. As with any research project, several problems developed. For example, the storage bin was constructed of carbon steel and when contacted with the wet activated carbon, corrosion was rampant. Considerable time was spent trying to keep the exhausted activated carbon feeding properly into the furnace. The moist adsorbent tended to "bridge" at the entrance to the furnace feed screw and finally a bin vibrator had to be installed to facilitate feeding.

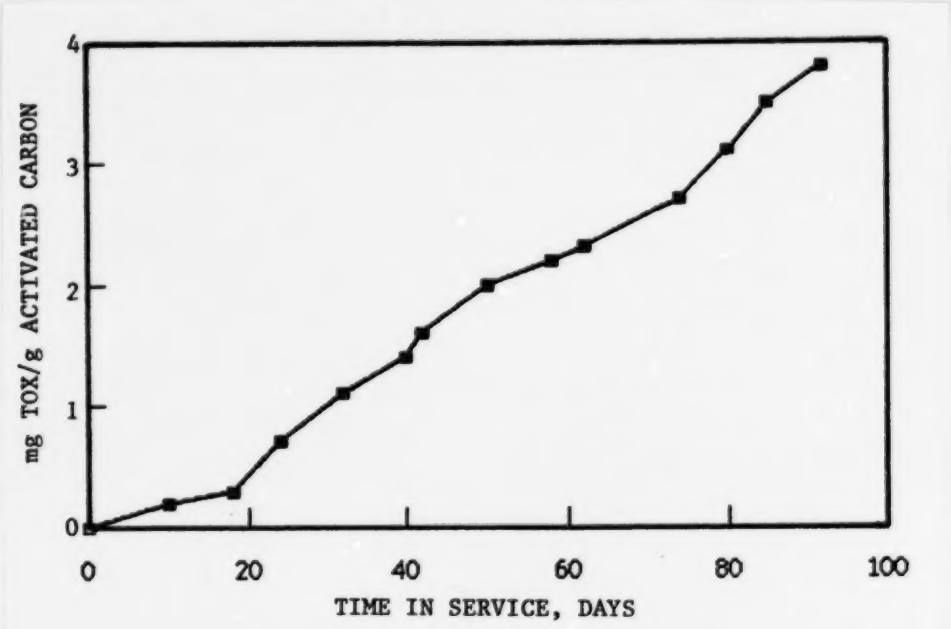

Figure 5. Averaged Total Organic Halogen Loadings on Virgin Activated Carbon

For the initial regeneration, the contact time for the activated carbon within the furnace was 20 minutes at a temperature of 900°C (1650°F). These conditions were selected by the furnace vendor on the basis of thermographic analyses and iodine numbers. The first activated carbon to be regenerated was the lignite base product. Unfortunately, because of inexperience, problems in handling the adsorbent resulted in over 17 percent (weight) loss of the activated carbon. As the operators gained experience in handling the exhausted activated carbon, losses declined. The following is an overview of each regeneration/exposure cycle. Details on the performance of the furnace and restoration measurements on the activated carbon are given later in this report.

Performance After First Regeneration

This 15-week long study period (September 12, 1978 to January 2, 1979) was conducted on approximately 93 percent regenerated and 7 percent virgin (makeup) activated carbon*. The THM concentration reached a peak of 202 ug/L in the applied water to the adsorbers. The average filter effluent THM concentration slightly exceeded 90 ug/L. Removal efficiences for THMs were essentially zero after 11 weeks.

For other organic solvents detected during the service period (Table 5), a considerable concentration difference was observed between applied water and average adsorber effluent, indicating better chlorinated solvent removal as compared to the virgin adsorption cycle. An anomoly exists in that non-

*by weight

TABLE 5. EFFECTIVENESS OF TREATMENT FOR SPECIFIC ORGANIC COMPOUNDS AFTER FIRST REGENERATION

Organic Compounds	Passaic River	After Conventional Treatment, Before Adsorption	After Adsorption		
			HD-1050	W-4	F-400
Aldrin, ug/L	ND	<0.01	<0.01	<0.01	<0.1
α-benzene hexachloride, ug/L	<0.01	<0.01	<0.01	<0.01	<0.1
β-benzene hexachloride, ug/L	ND-2.6 (0.35)	<0.01	<0.01	<0.01	<0.01
Carbon tetrachloride, ug/L	ND-0.6 (0.1)	ND-3.3 (0.5)	<0.1-1.4 (0.3)	ND-2.4 (0.5)	ND-0.5 (0.35)
Dieldrin, ug/L	<0.01	<0.01	ND	ND	ND
dilodomethane, ug/L	ND	ND-1.1 (0.7)	≤-0.4 (<0.3)	ND-1.3 (<0.3)	ND-1.3 (<0.3)
heptachlor epoxide, ug/L	ND-0.01 (0.01)	ND-0.01 (<0.01)	ND-0.01 (<0.0.01)	ND-0.01(<0.01)	ND-0.01 (<0.01)
heptachlor, ug/L	<0.01	<0.01	<0.01	ND	ND
PCB (arochlor 1254) ug/L (arochlor 1248) ug/L	0.2 0.2	ND ND	ND ND	ND ND	ND ND
p-dichlorobenzene, ug/L	<1	<1	ND	ND	ND
tetrachloroethylene, ug/L	<0.3	<0.3	ND	ND	ND
1,1,2,2-tetrachloroethane, ug/L	<0.3	<0.3	<0.3	<0.3	<0.3
1,1,1-trichloroethane, ug/L	<02	<2	<2	<2	<2
trichloroethylene, ug/L	<0.3-11.8 (2.3)	<0.3-3.9 (1.9)	<0.3-0.7 (0.4)	<0.3-1.7 (0.5)	<0.3-0.9 (0.5)
0,p-DDE, ug/L	<0.01	ND	ND	ND	ND
0,p-DDT, ug/L	<0.01	ND	ND	ND	ND
0,p-DDD, ug/L	<0.01	ND	ND	ND	ND

ND = none detected

THM halogenated solvents increased in concentration through the treatment plant prior to adsorption. This suggests contamination resulted from using solvents within the treatment plant or from contaminants in the chlorine used for disinfection. The chlorinated solvent concentration of the water prior to adsorption peaked at approximately 14 ug/L. The concentration of solvents in the effluent from the activated carbon during this period ranged as high as 7 ug/L. The primary solvent was carbon tetrachloride, a common contaminant of liquid chlorine. The activated carbon bed loading for TOX (excluding THMs) was approximately 2.5 mg/g. TOC removal reached a plateau of approximately 25 percent in 7 weeks and TOX removal plateaued at 40 percent in 5 weeks.

Performance After Second Regeneration

This portion of the project took place between April 24 and September 4, 1979. The non-THM volatile halogenated solvents exhibited better removal than those observed during the first regeneration cycle. The sum of the specific organics* reached as high as 28.8 ug/L in the adsorber influent and averaged 11 ug/L in the adsorber effluent. In addition, during this period raw water solvent concentrations were as high as 14 ug/L. Again, there seems to be an indication that halogenated solvent contamination was resulting from the treatment process (Table 6). TOX removal during this run was

*The total of peak concentrations in a weekly analysis

TABLE 6. EFFECTIVENESS OF TREATMENT FOR SPECIFIC ORGANIC COMPOUNDS AFTER SECOND REGENERATION

Organic Compounds	Passaic River	After Conventional Treatment, Before Adsorption	After Adsorption		
			HD-1030	WV-W	F-400
Aldrin, ng/L	<0.01	ND	ND	<0.01	<0.01
α-benzene hexachloride, ng/L	<0.01	ND	ND	ND	ND
β-benzene hexachloride, ng/L	<0.01-0.2 (0.02)	<0.01	<0.01	<0.01	<0.01
Carbon tetrachloride, ug/L	ND-2.6 (0.5)	<0.1-23.1 (1.4)	ND-5.8 (0.5)	ND-13.2 (1.2)	ND-0.6 (0.2)
Dieldrin, ng/L	ND	ND	<0.01	<0.01	<0.01
diiodomethane, ug/L	<0.3	<0.3	ND	ND	ND
heptachlor epoxide, ng/L	<0.01	<0.01	<0.01	<0.01	<0.01
heptachlor, ng/L	<0.01	<0.01	ND	ND	<0.01
PCB (arochlor 1254) ug/L	<0.06	<0.06	<0.06	<0.06	<0.06
(arochlor 1248) ug/L	<0.06	<0.06	<0.06	<0.06	<0.06
p-dichlorobenzene, ug/L	ND-9.3 (2.5)	ND-3.8 (1.1)	<1	<1	<1
tetrachloroethylene, ug/L	0.4	0.3	0.1	0.2	0.2
1,1,1-trichloroethane, ug/L	<2	<2	<2	<2	<2
trichloroethylene, ug/L	ND-1.4 (0.9)	<0.3-2.5 (1.0)	ND-2.7 (<0.3)	ND-0.6 (<0.3)	ND-0.6 (<0.3)
0,p-DDT, ng/L	<0.04	<0.04	<0.04	<0.04	<0.04
0,p-DDD, ng/L	ND-5.6 (0.37)	ND-0.2 (0.05)	ND-0.3 (0.04)	<0.04	<0.04

ND = none detected

extremely variable. No distinct plateau for TOX removal developed, yet overall, the loading of 2.5 mg TOX/g activated carbon is comparable to earlier runs. A 35 percent plateau of TOC removal was attained in approximately 5 weeks.

Performance After Third Regeneration

For a 20 week period between April and August 1980, the Drinking Water Research Division of U.S. EPA analyzed influent and effluent samples for "organic profiles" through the activated carbon adsorbers, By use of capillary column gas chromotograph with a flame ionization detector (14), profiles were generated that represent the complex mixture of trace organics in treated water. A solvent blank is shown at the top of Figure 6 and these peaks must be visually subtracted from the other chromatograms. Although strickly qualitative, the improvement in organic quality is evident from the first day this thrice regenerated activated carbon was put into service until late into the run (14 weeks) after the TOC removal had stabilized.

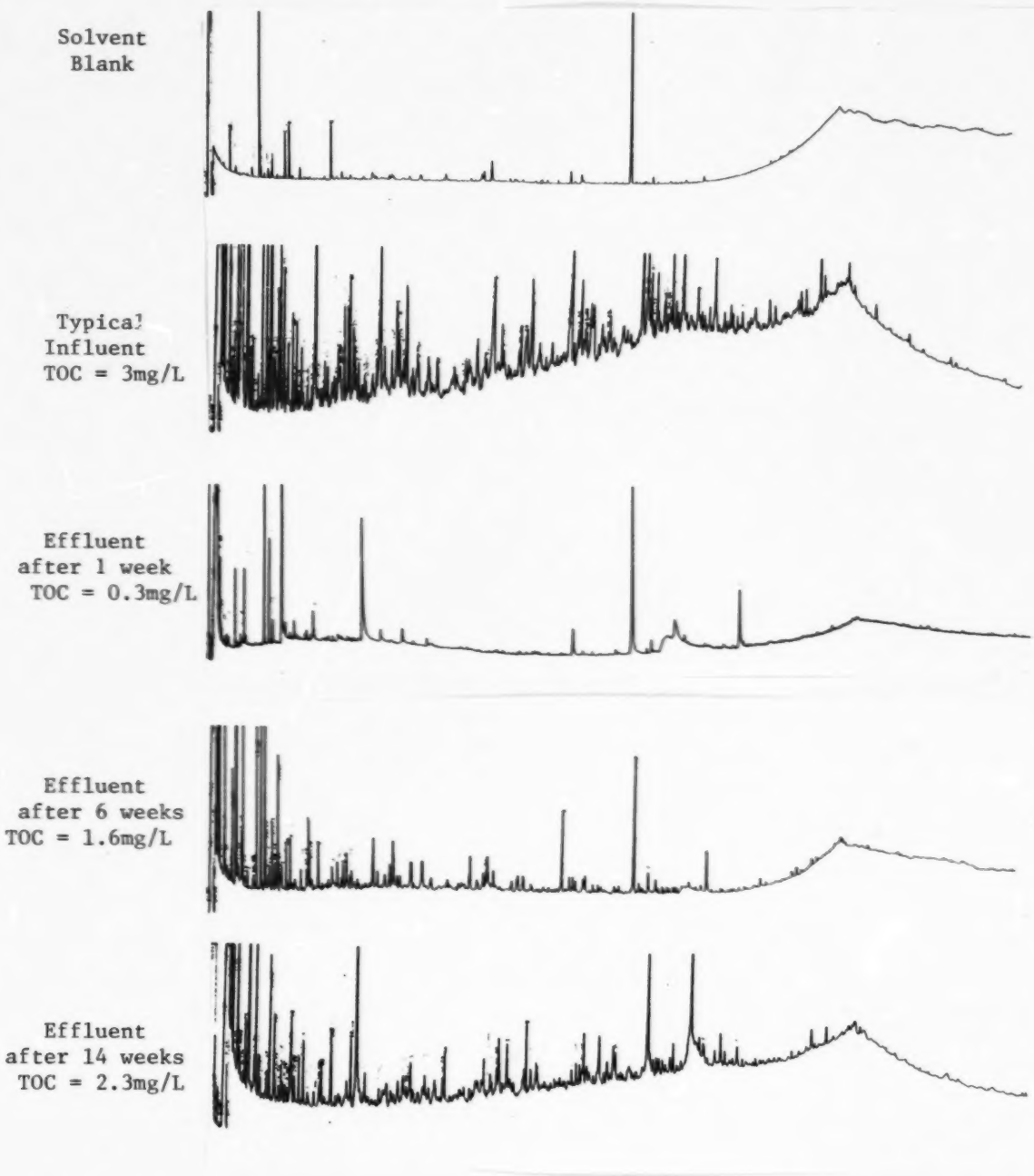

Figure 6. Capillary Column Chromatographic Profiles of Treated Passaic River Water Before and After Adsorption on Thrice-Regenerated Activated Carbon

SECTION 5

EFFECTIVENESS OF REGENERATION

Table 7 summarizes the furnace conditions and some of the characteristics of each type activated carbon before and after regeneration. The iodine numbers for the two coal-based carbons dropped during the first cycle and remained essentially constant for subsequent regenerations. The lignite-based carbon experienced an initial reduction in iodine number, but subsequent regenerations restored the iodine number to a near-virgin level. As indicated by the apparent density values, the process conditions used in the first regeneration resulted in an under-regeneration of the carbon.

TABLE 7. COMPARISON OF VIRGIN TO REGENERATED ACTIVATED CARBON PROPERTIES

Item	HD-1030				Barnebey VPG				Filtrasorb 400			
	Virgin	Cycle 1[a]	Cycle 2[a]	Cycle 3[a]	Virgin	Cycle 1[a]	Cycle 2[a]	Cycle 3[a]	Virgin	Cycle 1[a]	Cycle 2[a]	Cycle 3[a]
Regeneration Process Parameters:												
Residence Time (min.)	—	20	25	25	—	20	25	25	—	20	25	25
Zone A Temperature (°F)	—	1300	1500	1500	—	1300	1500	1500	—	1300	1500	1500
Zone B Temperature (°F)	—	1650	1650	1650	—	1650	1700	1700	—	1650	1700	1700
Carbon Layer Thickness (in.)	—	0.75	0.75	0.75	—	0.75	0.75	0.75	—	0.75	0.75	0.75
Carbon Properties (Ave.):												
Apparent Density (g/cc)	0.435	S-0.437 R-0.420	S-0.451 R-0.420	S-0.450 R-0.422	0.574	S-0.608 R-0.572	S-0.616 R-0.577	S-0.627 R-0.594	0.467	S-0.506 R-0.490	S-0.533 R-0.493	S-0.543 R-0.507
Iodine Number (mg/g)	488	S-416 R-488	S-426 R-581	S-473 R-617	850	S-711 R-761	S-678 R-807	S-643 R-758	1023	S-790 R-890	S-747 R-923	S-679 R-882
Ash Content (%)	13.5	R-14.2	R-16.1	R-17.3	6.8	R-7.6	R-7.9	R-9.3	6.7	R-7.4	R-7.8	R-8.9
Effective Size (mm)	0.80	R-0.78	R-0.78	R-0.72	0.65	R-0.76	R-0.71	R-0.64	0.63	R-0.74	R-0.75	R-0.67

[a]Regeneration Cycle S = Spent or Exhausted Activated Carbon; R = Regenerated Activated Carbon

Conditions were adjusted for the second and third regenerations. These adjustments resulted in a slight recovery of iodine number for the coal-based carbons and a significant improvement in properties for the lignite-based carbon. According to Inhoffer and McGinnis (15), a reasonable interpretation of this result is that the lignite-based carbon is more reactive than the coal-based carbons and that the effects of under-regeneration were therefore more readily reversed. It should be noted that this recovery was not achieved at the expense of increased carbon losses. In addition, it should be mentioned that it might have been possible to obtain similar property recovery for the coal-based carbons by regeneration at higher temperatures, or longer times, or both.

Effective size is defined as the sieve opening through which 10% of the carbon particles will pass. Therefore, a reduction in effective size is indicative of abrasion of the carbon while in-service. The data indicates an initial increase in effective size, probably the results of washing out of fines present in the virgin carbon. Subsequent cycles indicate a general trend of reduction in effective size for all three carbons.

The data for ash content of the activated carbon indicates a general increase over the three regeneration cycles. To determine if the accumulation of inorganic compounds could be identified, both water and activated carbon samples were shipped to Simms and Rickey (16) for Proton Induced X-Ray Emission (PIXE) analyses. Table 8 shows the PIXE profile of the water at the Little Falls filtration Plant for one date during the use of twice regenerated activated carbon . Of the 40 elements reported, only calcium and manganese appeared to be retained on the activated carbon.

To further examine this issue, a few grams of exhausted, regenerated (quenched), and virgin activated carbon were placed in bottles containing one liter of distilled water. After intense mixing for one hour, the activated carbon was filtered through glass wool and the filtrate analyzed. Those analytical results (with background substracted) are given in Table 9. This manner of extraction is crude, and the PIXE technique limited, but none of these elements are obvious contributors (< 20 percent) to the ash buildup on the regenerated activated carbon.

Because sulfite is used as a dechlorinating agent, perhaps sulfur conaining compounds and chlorides are accumulating on the adsorbents, thus causing the ash content to increase. Some circumstantial evidence lends credibility to this speculation. Examine the behavior of free chlorine in Figure 7. The water applied to the activated carbon generally contained between 0.5 mg/L and 1.5 mg/L free chlorine after sulfite treatment. During the virgin cycle, no free chlorine was detected after the water passed through the adsorbents indicating the chlorine was reduced. Following the first regeneration, however, free chlorine penetrated the system after 13 weeks. Only three weeks of service passed before chlorine penetrated the twice regenerated activated carbon, and after the third regeneration, at least 0.2 mg/L free chlorine was detected in the effluent at the outset of resuming service.

The total organic carbon concentrations before and after adsorption on the virgin and regenerated activated carbon are illustrated in Figure 8. Approximately 20 percent decline in TOC adsorption capacity was calculated between the virgin and the first regeneration cycle. The second and third regenertions, however, proved to increase the TOC capacity (relative to the virgin cycle) by 17 percent and 74 percent, respectively.

In a separate adsorption capacity study, virgin and twice regenerated F-400 granular activated carbon were compared in an adsorption isotherm study. The details of the test have been reported (17) but to summarize,

TABLE 8. ANALYSIS OF RAW AND TREATED PASSAIC RIVER WATER BY PROTON INDUCED X-RAY EMISSION

Element	Concentration, ug/L				
	Intake	Finished Water (Influent to Act. Carbon)	Activated Carbon Effluent		
			HD-1030	WV-W	F-400
Arsenic (As)	<0.5	<0.5	<0.5	<0.5	<0.5
Antimony (Sb)	<2.2	<2.2	<2.2	<2.2	2.2
Barium (Ba)	27	27	20	35	14
Bromide (Br)	81	47	61	56	61
Potassium (K)	3047	2777	2691	2774	2855
Calcium (Ca)	30344	29519	28234	28600	28908
Cesium (Cs)	<4.7	<4.7	<4.7	<4.7	<4.7
Chromium (Cr)	2.0	<0.5	<0.5	<0.5	.78
Cobalt (c0)	<8.1	<8.1	<8.1	<8.1	<8.1
Copper (cu)	10	5.8	15	7.3	18
Gallium (Ga)	<1	<1	<1	<1	<1
Germanium (Ge)	<1	<1	<1	<1	<1
Gold (Au)	<3	<3	<3	<3	<3
Indium (In)	<2.2	<2.2	<2.2	<2.2	<2.2
Iodide (I)	6.3	5.2	6.8	3.7	<2
Iron (Fe)	787	13	10	12	13
Lanthanum (La)	<6.2	<6.2	<6.2	<6.2	<6.2
Lead (Pb)	4.1	1.4	3.3	1.3	2.0
Manganese (Mn)	147	4.8	1.3	<1	<1
Mercury (Hg)	<1.1	<1.1	<1.1	<1.1	<1.1
Molybdenum (Mo)	<2.2	<2.2	<2.2	<2.2	<2.2
Nickel (Ni)	5.5	5.1	3.7	3.4	4.3
Palladium (Pd)	<2.2	<2.2	<2.2	<2.2	<2.2
Platinum (Pt)	<3	<3	<3	<3	<3
Potassium (k)	3047	2777	2691	2774	2855
Rubidium (Rb)	<1	2	1.9	2.2	1.9
Scandium (Sc)	<303.4	<303.4	<303.4	<303.4	<303.4
Selenium (Se)	<1	<1	<1	<1	<1
Silver (Ag)	<2.2	<2.2	<2.2	<2.2	<2.2
Strontium (Sr)	113	117	115	113	113
Tantalum (Ta)	<3	<3	<3	<3	<3
Tellurium (Te)	<2.2	<2.2	<2.2	<2.2	<2.2
Thallium (Tl)	<3	<3	<3	<3	<3
Tin (Sn)	<2.2	<2.2	<2.2	<2.2	<2.2
Titanium (Ti)	40	<3.3	<3.3	<3.3	<3.3
Vanadium (V)	<1.3	2.8	2.8	3.2	3.6
Wolfram (W)	<3	<3	<3	<3	<3
Zinc (Zn)	11	6.5	11	50	13

TABLE 9. PIXE ANALYSES OF DISTILLED WATER EXTRACTS FROM GRANULAR ACTIVATED CARBON

Element	Concentration, ug/L					
	F-400			HD-1030		
	Virgin	Exhausted	Regenerated*	Virgin	Exhausted	Regenerated*
Arsenic (As)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Antimony (Sb)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Barium (Ba)	<5	32	8	<5	<5	9
Bismuth (Bi)	<3	<3	<3	<3	<3	<3
Bromide (Br)	0.2	211	190	0.6	79	153
Potassium (K)	21	134	249	88	139	<1
Calcium (Ca)	978	9900	3554	9936	4658	4722
Cesium (Cs)	<3/5	<3.5	<3.5	<3.5	<3.5	<3.5
Chromium (Cr)	0.8	3.3	5.0	<0.5	1.3	1.1
Cobalt (Co)	<7	<7	<7	<7	<7	<7
Copper (Cu)	<1	<1	13	<1	<1	<1
Gallium (Ga)	1.1	<1	<1	<1	<1	<1
Germanium (Ge)	<1	<1	<1	<1	<1	<1
Gold (Au)	<3	<3	<3	<3	<3	<3
Indium (In)	<1	<1	<1	<1	<1	<1
Iodide (I)	<1	1.9	<1	<1	<1	<1
Iron (Fe)	51	68	431	25	87	142
Lanthanum (La)	<5	<5	<5	<5	<5	<5
Lead (Pb)	1.33	1.53	3.33	0.06	0.63	0.43
Manganese (Mn)	1.5	235	250	55	9	45
Mercury (Hg)	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1
Molybdenum (Mo)	<1	<1	<1	<1	<1	<1
Nickel (Ni)	<1	5.31	5.41	5.21	1.91	.31
Palladium (Pd)	<1	<1	<1	<1	<1	<1
Platinum (Pt)	<3	<3	<3	<3	<3	<3
Radium (Ra)	<5.2	<5.2	<5.2	<5.2	<5.2	<5.2
Rubidium (Rb)	<1	<1	<1	<1	<1	<1
Scandium (Sc)	<103	<103	<103	<103	<103	<103
Selenium (Se)	<1	<1	<1	<1	<1	<1
Silver (Ag)	<1	<1	<1	<1	<1	<1
Strontium (Sr)	30.7	667	25.7	156.7	24.7	44.7
Tantalum (Ta)	<3	<3	<3	<3	<3	<3
Tellurium (Te)	<1	<1	<1	<1	<1	<1
Thallium (Tl)	<3	<3	<3	<3	<3	<3
Tin (Sn)	<1	<1	<1	<1	<1	<1
Titanium (Ti)	9.1	<3.4	27	7.1	6.2	18
Uranium (U)	<9.8	<9.1	<9.1	<9.1	<9.1	<9.1
Vanadium (V)	<1.8	<1.8	<1.8	<1.8	2.2	<1.8
Wolfram (W)	<3	<3	<3	<3	<3	<3
Zinc (Zn)	<1	20	72	4	4	<1

*after quenching

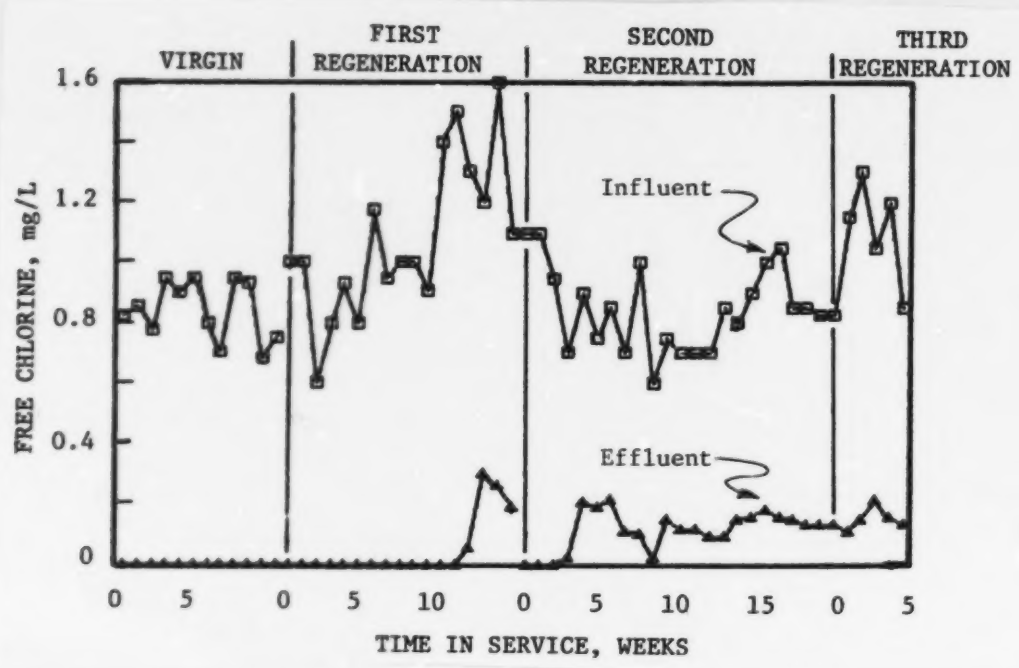

Figure 7. Removal of Free Chlorine Residual on Virgin and Regenerated Activated Carbon

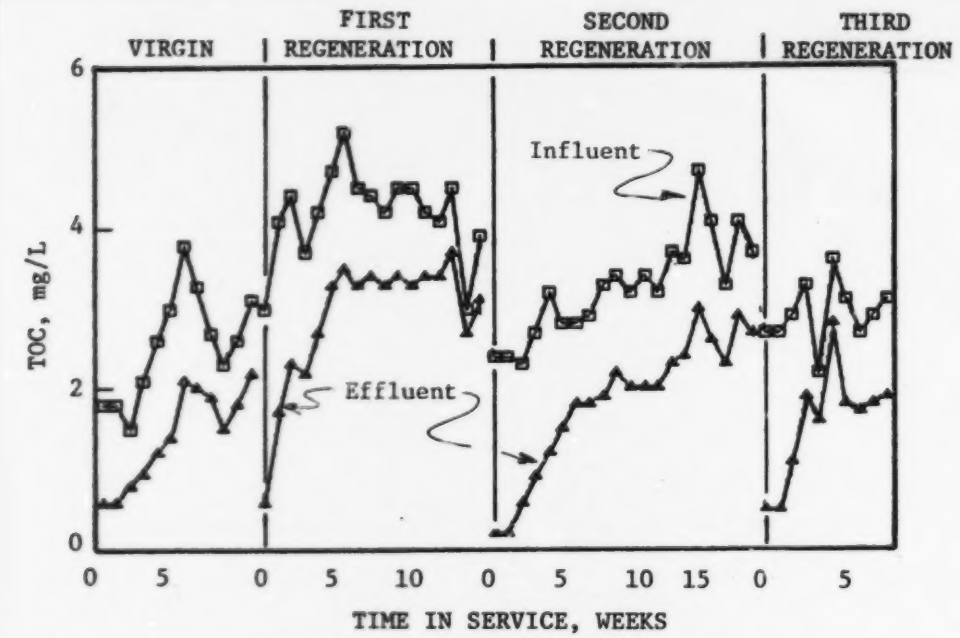

Figure 8. Total Organic Carbon Removal on Virgin and Regenerated Activated Carbon

dechlorinated Cincinnati, Ohio tap water was used as an adsorbate (TOC = 2.0 mg/L) and although virgin activated carbon seemingly had a slightly higher adsorption capacity, the regression line of the regenerated activated carbon (Figure 9) is adjacent to the lower confidence interval curve. This was interpreted that the twice regenerated activated carbon was not more than 2.5 percent less efficient in TOC adsorption capacity than virgin material.

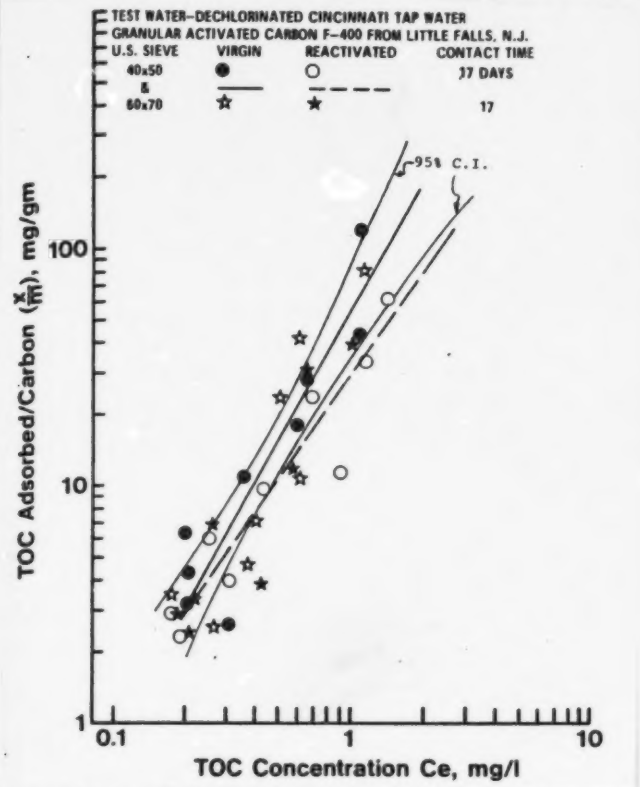

Figure 9. Comparison of Total Organic Carbon Isotherms on Virgin and Twice Regenerated Activated Carbon (17)

Both UV absorbance and fluorescence data were collected. The latter parameter has been proposed by Sylvia (18) to be a good operational monitor for a regeneration system. Many of the European installations, however, measure adsorption performance with UV extinction (absorbance*) and Wissenhorn (19), for example, showed virgin activated carbon and regenerated activated carbon were nearly equivalent. Figure 10 summarizes the performance of the adsorbents before and after regeneration at the Little Falls plant as measured by RFM**. The RFM data, calcuated as loading (i.e., taking flow and quantities of adsorbents into account), is shown in Figure 12. During the first regeneration cycle, the average RFM value of the influent was almost twice that of any other cycle. This might account for the 143 percent increase in RFM removal after one regeneration. After the second regeneration, the RFM capacity was still higher than during the virgin

*@ 254 nm

** Rapid Fluorometric Method (see Table 3)

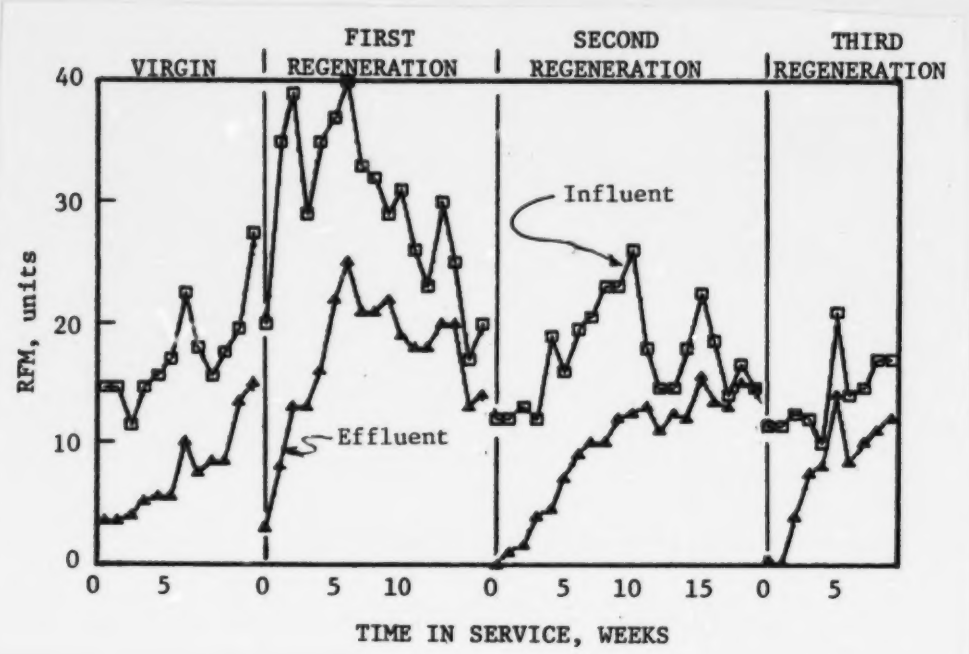

Figure 10. Effectiveness of Adsorption on Activated Carbon Measured by Fluorescence (RFM)

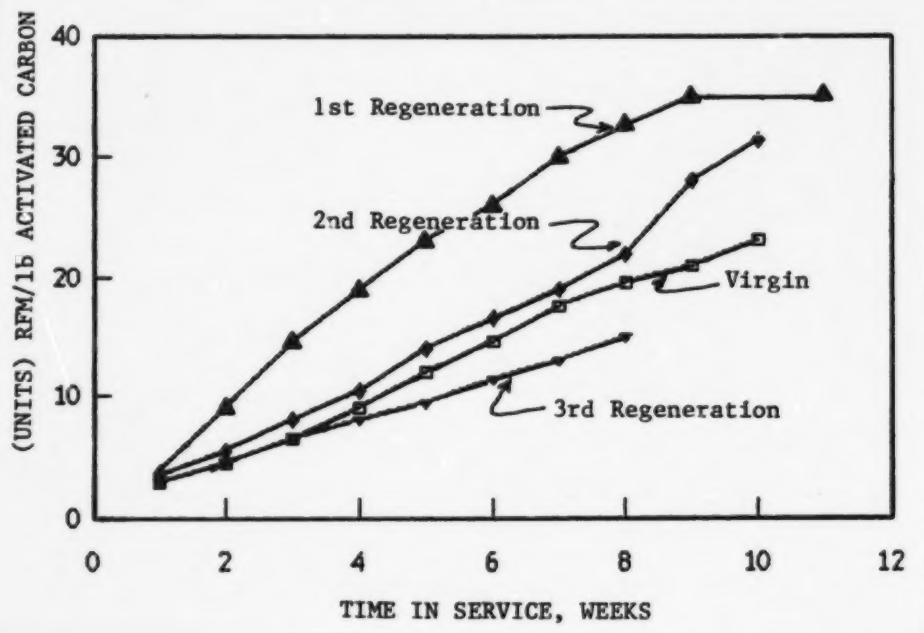

Figure 11. Comparison of Fluorescence Loading on Virgin and Regenerated Activated Carbon

cycle (+47.5 percent) but it declined (17 percent) after the third regeneration. The UV absorbance difference was -20 percent for the first regeneration, -12 percent and -27 percent for the second and third cycle, respectively, relative to the virgin cycle.

Figure 12 is the summary of total organic halogen (TOX) loadings before and after regeneration of the activated carbon. The adsorbents had the greatest TOX removal capacityin the virgin state, however, regeneration consistently restored approximately 50 percent of the virgin capacity.

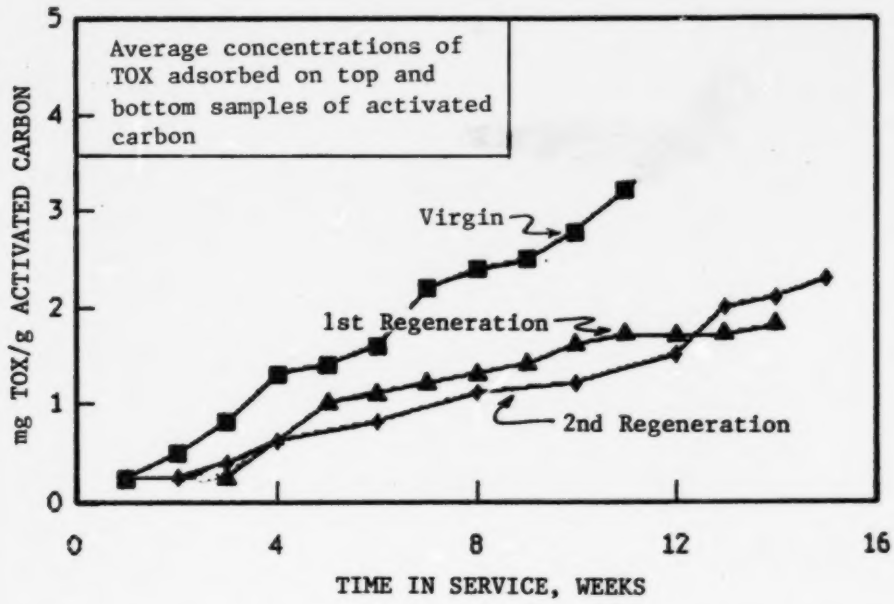

Figure 12. Comparison of Total Organic Halogen Loading on Virgin and Regenerated Activated Carbon

Following the second regeneration, samples of activated carbon were shipped to Georgia Institute of Technology for surface properties analyses. Using a Digisorb 2500*, exhausted, virgin, and regenerated activated carbon were compared for pore volume distribution, surface area distribution, and adsorption and desorption isotherms. Some of those results are shown in Figures 13 and 14. A noticable difference exits between the coal base (F-400) and the lignite base (HD-1030) activated carbon. The HD-1030 has a large pore volume between 30 and 50 angstroms (Å), where the bituminous coal base adsorbent has most of its pore volume below 30Å. Both the pore volume and pore surface area declined about 25 percent during regeneration.

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*Micrometrics Instrument Corp., Norcross, GA. Pore sizes ranging from 20 angstroms to 600 angstroms are determined by nitrogen adsorption.

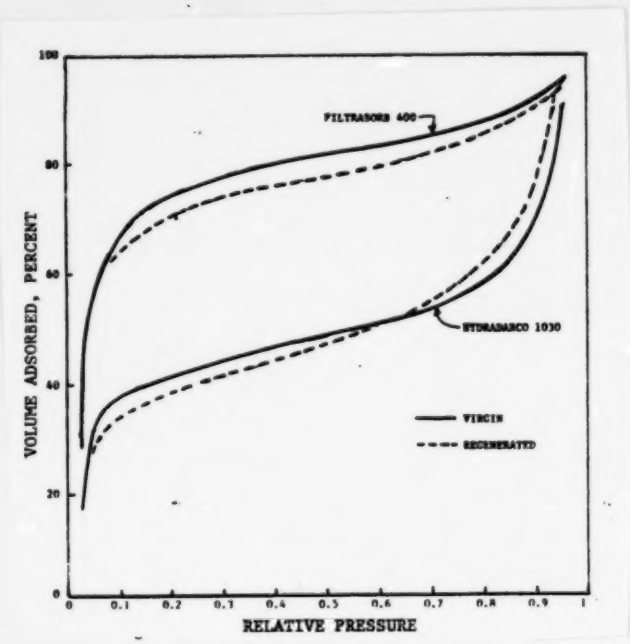

Figure 13. Comparison of Virgin and Twice Regenerated Activated Carbon Using Desorption Isotherms

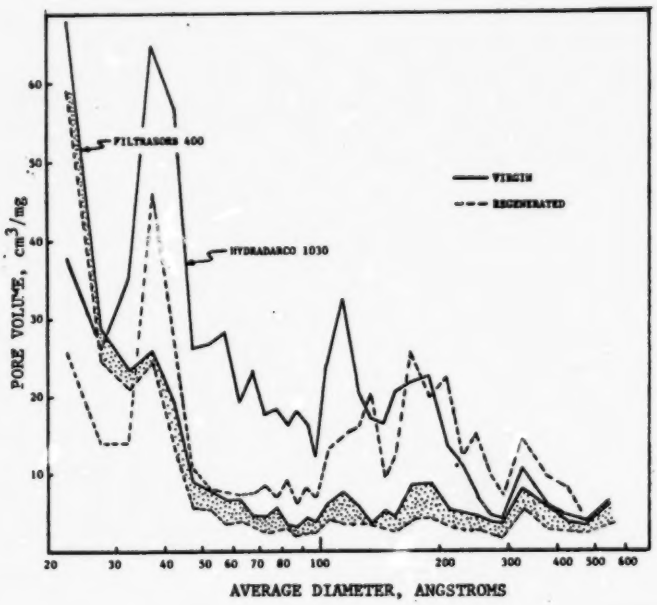

Figure 14. Comparison of Pore Volumes for Virgin and Twice Regenerated Activated Carbon

SECTION 5

DISCUSSION OF RESULTS

Between 1978 and 1981, the Little Falls Filtration Plant, which treats water from the Passaic River, was the location of an activated carbon adsorption study that included 3 on-site regenerations with an electric furnace. The water quality in the Passaic River is constantly changing, therefore, the residual chlorine and organic loading to the activated carbon varied widely over the course of this project. Certain trends, however, are clear from this study.

With respect to the performance of the activated carbon, the background organics (TOC) and halogenated compounds (TOX) rapidly broke through and reached steady state removal within a few weeks. Free chlorine eventually penetrated the activated carbon beds and trihalomethanes continued to be produced in the effluent.

The infrared furnace represents a comparatively new development for thermally regenerating activated carbon. Because the activated carbon is not mechanically agitated as it passes through the electric furnace, attrition losses are low. The cumulative losses from the adsorber through the furnace and back to the adsorber averaged 5 percent*. The furnace is not complicated to use by water works personnel but training is necessary. Additionally, some mechanical problems were experienced. Several glo-bars (the infrared heat source) had to be replaced and the conveyor belt failed once during the study. A discussion of the belt problems and its replacement are presented in Appendix B.

The effectiveness of regeneration was monitored several ways. The traditional parameters such as iodine number, apparent density and effective size were used to determine the furnace operating conditions. Those indices (shown in Table 10) suggest very effective restoration. The ash content, however, steadily increased, indicating inorganic buildup on the activated carbon. This is perhaps why the TOX capacity failed to return to the virgin state and free chlorine residuals were able to penetrate the activated carbon beds after the first regeneration cycle. The decline in the pore volume and pore area of the activated carbon may have resulted in an increase of large diameter pores (>100Å) and may be the reason the TOC capacity increased after regeneration.

Monitoring fluorescence (RFM) and ultraviolet absorbance in the water before and after adsorption is easy and inexpensive to do, but do they accurately describe the behavior of a more specific organic measurements such as the TOC. Examine Figures 8 and 10. The RFM appears to generally predict TOC behavior but upon calculating the actual differences, (Table 10), neither RFM nor UV absorbance are very useful surrogates.

*by weight

TABLE 10. COMPARISON OF REGENERATED TO VIRGIN ACTIVATED CARBON, SUMMARY

Parameter	First Regeneration	Second Regeneration	Third Regeneration
Iodine number, mg/g	good	excellent	excellent
Apparent density, g/cm^3	excellent	excellent	excellent
Effective size, mm	good*	excellent	excellent
Ash content, %	excellent	good*	poor*
Total organic carbon, mg/g	good	good*	poor*
Total organic halogen, mg/g	poor	poor	NA
Free residual chlorine, mg/g	excellent	good	fair
RFM (fluorescence), units/g	poor	poor	good
UV absorbance, units/g	good	good	poor
Pore volume, cm^3/g	NA	poor	NA
Pore area, m^2/g	NA	poor	NA
TOC isotherm, mg/g	NA	excellent	NA
Trihalomethane Removal	fair	poor	poor

where: excellent = $\leq$ 10% difference
good = 11 to 20%
fair = 21 to 30%
poor = $\geq$ 31%
NA = not available

*indicates a positive difference (i.e. increase after regeneration)

Regeneration Costs

The infrared furnace had an average energy consumption of 0.7 kilowatt (kW) per pound of activated carbon. Assuming a unit power cost of $0.03/kW-hr, the energy portion of the regeneration cost is equivalent to approximately $0.06 per kg (2.5¢/lb) regenerated. Activated carbon losses from handling and regeneration (losses in these two steps cound not be monitored separately) averaged 5 percent* which is equivalent to $0.06/kg regenerated. These costs exclude the high losses experienced in the first regeneration attempt with the HD-1030 activated carbon before the feed system functioned properly. Materials and labor for operating and maintaining the furnace were estimated to be $0.33/kg to $0.40/kg (15 cents to 20 cents/lb) (15). The total direct costs of regeneration, excluding amortized furnace and appurtenances, was therefore, approximately $0.45/kg to $0.52/kg (20 cents to 25 cents per pound).

*by weight

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APPENDIX A

ORGANIC ANALYSIS METHODOLOGY

ISOLATION AND CONCENTRATION TECHNIQUES

The following methods of sample preparation for volatile halogenated hydrocarbons were evaluated during this study.

a. Gas stripping of aqueous solutions.

b. Heated head space analysis.

c. Pentane extraction.

A discussion of the merits and limitations of each sample preparation technique is given below.

Inert gas purging of an aqueous solution was performed by a commerically available instrument* and is similar in principal to the method proposed by Bellar.** After purging the volatile materials from solution, the effluent gas stream is passed over an adsorbent column that exhibits selectivity for halogenated species. The trap material consists of 2/3 Tenax g.c. + 1/3 silica gel Type 15. The trap column is thermally desorbed and the gas evolved is swept onto the head of an analytical gas chromatographic column at 40°C. Detection of the effluent from the gas chromatograph (gc) is obtained by use of a halogen specific Hall Model 700† electrolytic conductivity detector.

Although this procedure is recommended by U.S. EPA, analytical determinations made by the procedure exhibitied non linear and somewhat erractic responses for fully chlorinated hydrocarbons, e.g., CCl_4 and CCl_2CCl_2. The condition of nonlinearity was remedied by the use of an elevated temperature purging procedure. This modification allowed the sample vessel to be heated to 80°C. The change in purging temperature enhanced the transfer of volatile materials to the gas phase reducing the purge time in excess of 70%. An overall reduction in analysis time from 72 to 32 minutes was produced by an

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* Tekmar liquid sample concentrator, Tekmar, Inc., Cincinnati, Ohio.

**Bellar T. and Lichtenberg, J. "The Determination of Volatile Organic Compounds at the ug/L Level in Water by Gas Chromatography", EPA 600/4-74-1009.

† Tracor Inst., Austin, Texas

additional modification, the reduction of analytical column length. However, the time savings was offset by a reduction in chromatographic resolution, which was a direct result of employing a shorter chromatographic column. Enhancement in calibration plot linearity was obtained by this method especially for CCl_4 and CCl_2CCl_2.

Minimum detectability for both gas purging techniques, utilizing a Hall Model 700 Detector is within the range of 0.1 to 1.0 ppb for the following light halogenated hydrocarbons:

1. CH_2Cl_2
2. $CHCl_3$
3. CH_3CCl_3
4. CCl_4
5. $CHCl_2Br$
6. $CHClBr_2$
7. CCl_2CCl_2
8. $CHBr_3$
9. $CHCl_2CHCl_2$
10. $1,2\text{-}Cl_2C_6H_4$
11. $1,2,4\text{-}Cl_3C_6H_3$

Both purging techniques exhibited adequate sensitivity for most applications to raw and finished waters, the shortcoming of the method was the difficulty in converting to an automated technique, which is desirable for many laboratory applications.

Heated head space analysis was evaluated and showed potential for compounds with boiling points up to bromoform. It was noted upon repeated injections of 1 to 5 mL of gas that water vapor caused a degradation in column performance. The pentane extraction preparation technique was found most desirable in that it decreased analysis time to 20 minutes for the trihalomethanes and enhanced the limits of detection for most compounds by a factor of ten or more. This technique also is preferable for automated analyses. The limitation for extraction when using packed columns and an electron capture detector, is a decrease in the number of halogenated hydrocarbons that can be detected. This is because of isothermal column operation. Thus, the halobenzenes are not eluted from the column because of their high boiling points. This situation may be considered a handicap by some; but many advantages are apparent and are listed in the discussion below.

Column Selection

Column materials for volatile halogenated hydrocarbon separation were narrowed to the following:

1. Tenax g.c. 60/80 mesh - porous polymer
2. Chromosorb 101 & 102 - porous polymers
3. Carbopack C + 0.1% CW 15M, 100/120 mesh supelocoport.

Tenax g.c. proved adequate; but when temperature programmed, using a Hall 700 detector, above 200°C bleed became a problem. Chromosorbs 101 and 102 are similar to tenax g.c. and were not evaluated, because similar bleed problems were anticipated. Carbopack C + 0.1% SP1000 produced undesirable

tailing when coupled to a Hall detector and temperature programmed. In addition degradation of resolution ensued in only a short period of time (1 - 2 weeks). Carbopack C + 0.1% SP1000 was thus deemed undesirable. Twenty percent SP2100 + 0.1% CW 15M on 100/120 supelcoport proved successful for resolution of many components and retained efficient after long periods of use (> 6 months).

Pesticides and Polychlorinated Biphenyls

The analytical methods used for the analysis of organochlorine pesticides and polychlorinated biphenyls are those methods recommended by U.S. EPA in NPDES Appendix A (Fed. Feg. 38, #75, Pt. II). The only deviation from the recommended procedure was that the column material for GLC differed from those suggested and consisted of 1.95% sp 2401 + 1.5% sp 2250 on supelcoport 100/120 mesh (Supelco Company, Bellefonte, PA). Each sample was examined for the following common group 1 organo chlorine pesticides:

A-BHC	p, p'd - DDE
B-BHC	Dieldrin
Heptachlor	o,p' - DDT
Heptachlor expoxide	p,p' - DDD
	p,p' - DDT

Minimun detectability for most pesticides using a 500 mL initial water sample ranged from less than 1 to approximately 10 parts per trillion (mg/L). Electron capturing components present in the solvent did not interfere with the determination of pesticides or PCBs. The one interferring peak encountered eluted earlier than chromatographic peaks of interest. The minimum detectability for PCBs (based on aroclor 1242) is approximately 0.05 ppb.

Variation of Halogenated Materials in the Treatment Plant

Because most of the sampling was conducted on a grab basis, it was necessary to obtain some indication of the variation in concentration of all monitored chlorinated compounds in both raw and finished waters at the Little Falls Filtration Plant. Plant personnel obtained all samples for this survey. Sample containers were solvent washed and baked at 250°C before use. Sampling was conducted every eight hours for a period of five days, and all samples for volatile halogenated hydrocarbon analysis were fixed with Na_2SO_4 in the field. The n-pentane extraction procedure was used for the isolation of volatile halogenated hydrocarbons while an exhaustive stream distillation/extraction procedure was employed to obtain a suitable extract for high boiling halogenated hydrocarbons.

The variation in trihalomethane was quite dramatic for the finished water samples, ranging from 34 to 90. The raw water trihalomethane concentrations were, of course, much smaller than those of the finished water and

only vary to a significant extent for chloroform and dichlorobromomethane (the species present in the largest concentration). The volatile compounds observed that caused major concern were carbon tetrachloride and tetrachloroethylene. The concentration behavior of these two compounds over the sampling period indicates quite clearly that these two organic compounds were being discharged upstream. In the case of CCl_4, occurrence in the raw water is periodic and the CCl_4 concentration actually increased within the treatment plant. The source of CCl_4, therefore, is likely the chlorine used for disinfection.

Higher boiling chlorinated hydrocarbons were not detected, either in the raw or finished water during this monitoring survey, although they had been detected previously. The minimum detectability of PCBs (as Arochlor 1242) is 0.35 ppb and approximately 10 to 20 parts per trillion for most organochlorine pesticides.

Precision and Accuracy of Methods

Volatile Organic Analyses

The purging method used at the beginning of this project exhibited precision in the range of 10-20% for all of the standard compounds. The accuracy was not measured for this technique. The precision and accuracy of the n-pentane extraction technique is shown in Table A-1. For gas chromatographic systems with automatic data handling capabilities, recovery runs can be used to calibrate the data system.

TABLE A-1. PRECISION AND ACCURACY OF n-PENTANE EXTRACTION METHOD

Run	$CHCl_3$	CCl_4	$CHCl_2Br$	$CHClBr_2$	CCl_2CCl_2	$CHBr_3$	$CHCl_2CHCl_2$
1	14.73	16.21	14.70	14.42	16.62	28.81	15.92
2	14.80	17.13	15.67	14.07	17.47	27.46	15.28
3	13.98	15.61	13.91	13.66	15.62	27.55	15.27
S.D. ppb	0.45	0.77	0.88	0.38	0.93	0.76	0.37
% coefficient variation	3.1	4.7	6.0	2.7	5.6	2.7	2.4
True Value	14.97	15.99	14.80	14.50	16.23	28.89	15.85
$\pm$ % Error	-3.1	+1.9	-0.3	+3.1	+2.1	-3.3	-.2.3
% Recovery	88	98	100	90	97	88	100

APPENDIX B

REGENERATION FURNACE CONVEYOR BELT PROBLEMS

Shirco, Inc

2451 Stemmons Freeway • Dallas, Texas 75207 • (AC 214) 630-7511

December 4, 1979

Dr. Tom Love
U.S. EPA
26 West St. Clair St.
Cincinnati, Ohio 45268

SUBJECT: Passaic Valley Infrared Carbon Regeneration Furnace - Experience with the Woven Wire Conveyor Belt

Dear Tom:

The past two years of operations at Passaic Valley have provided us with much valuable experience in terms of both the mechanical design and the process performance aspects of the infrared furnace. One of the key mechanical components of the furnace is the woven wire conveyor belt, which transports the carbon through the unit. As we discussed earlier this week, it is timely to summarize the experience to date with this component.

The woven wire conveyor belt used in the infrared furnace is manufactured to our specification by one of several suppliers. The key areas of the belt specifications are the mesh design and the wire alloy, selections of which depend on the specific applications of the furnace.

Characteristics of the standard belts which we use for the incineration and carbon regeneration applications are summarized in Table 1. The incineration furnace belt is made from 14 gauge wire and has a nominal mesh opening of 0.060 inches. In our development of a specification for the carbon regeneration belt, we considered use of the incineration weave and found that small carbon particles filtered through the belt much to readily. After evaluation of several alternatives, we selected a weave fabricated from 18 gauge wire having a characteristic mesh opening of 0.017 inches. Use of the smaller diameter wire reduces the effective cross sectional area of the belt in the direction of belt tension and therefore reduces the margin of safety in terms of elevated temperatures strength. In addition, it was recognized that the smaller diameter wire would tend to have a shorter corrosion life. However, at the time of its selection this weave represented the best available compromise between mechanical design considerations and the carbon loss factor.

Our standard wire alloy for both the sludge incineration and carbon regeneration applications is Columbium-stabilized 35% Ni, 19% Cr. This alloy is considered to be general purpose, having good elevated temperature mechanical properties and good corrosion resistance in a variety of environments. However, we have supplied furnaces with belts of other alloys, such as Type 310 stainless steel and Type 314 stainless steel. We have a continuing program of evaluation of alternate alloys for specific applications using our pilot furnace and our laboratory facilities.

The belt history of the Passaic unit is summarized in Table 2. The original belt used in the Passaic furnace was the standard carbon weave and was made from Type 310 stainless steel wire. Near the end of the first regeneration cycle, this belt developed waviness along one edge. A decision was made to replace the belt prior to beginning of the second cycle, and this was accomplished in December, 1978. Examination of the belt indicated that its thickness had been decreased from a new value of 0.2" to a value of 0.16". This permanent reduction in thickness was attributed to over-pinching of the belt in the drive system. As indicated in Figure 1, the force necessary to drive the belt is obtained by pinching the belt on the drive drum by means of the so-called pinch drum. With the original pinch adjustment mechanism, it was comparatively easy to over-pinch the belt. Over-pinching has not been experienced with our standard sludge belt. We therefore concluded that the smaller cross-sectional area and wire diameter of the carbon weave make it more sensitive to pinch loading conditions. The waviness observed on one side of the belt was due to over pinching on that side, which produced additional elongation of the belt on that side. Modifications were made to the Passaic pinch system to facilitate uniform adjustment and limit maximum adjustment. By way of reference, the original belt cost approximately $1500, and during its life was used to regenerate approximately 50,000 lbs of carbon. Therefore, the maintenance cost associated with the belt replacement was equivalent to approximately 3 cents per lb of carbon regenerated, which is on the order of the cost of energy for regeneration.

The replacement belt was again made in the standard carbon weave, but the alloy was Columbium-stablized 35% Ni, 19% Cr. This alloy was selected because of its strength is slightly greater than that of Type 310 stainless steel. As shown in Table 2, this belt lasted for approximately 1,000 operating hours. In November 1979, during the middle of third regeneration, this belt began to show signs of deterioration along its edges. Examination revealed the waviness observed in the original belt, along with signs of corrosive attack of the wires along the edge of the belt. Therefore, a decision was made to replace the belt and this was accomplished in November of 1979, The second belt had been used to regenerate approximately 75,000 lbs of carbon. Since the replacement cost was approximately $2,000, the cost of belt replacement again equated to approximately 3 cents per lb of carbon regenerated.

An analysis of the second belt has been completed. Again, it had experienced the reduction in thickness associated with over-pinching. Subsequent microanalysis of belt wire samples revealed thick layers of scale on the belt wires in the primary region of damage. Therefore, it was concluded that belt life was being limited by a combination of over-pinching and corrosive attack of the wires. These effects are coupled in that over-pinching intends to crack any protective scale layer formed on the belt wires and expose fresh wire material to further attack by corrosive compounds present in the regeneration atmosphere.

As I mentioned, during the same time period we have had similar experiences in our full scale industrial granular carbon regeneration furnace in Louisiana. Our efforts to improve belt life have concentrated on two areas: first, we have taken steps to modify at the pinch adjustment design to minimize possibility of over-pinching This modification has taken the form of a spring-loaded pinch system, in which coil springs are adjusted to apply uniform pressure of the proper level to each of the pinch roller. In addition, we have worked with our belt suppliers to develop a weave

which is less susceptible to permanent deformation under conditions of over-pinching. The resulting weave is shown as the third entry of Table 1. It has approximately the same cross sectional area as our standard sludge weave, but has a characteristic of opening of 0.020", nearly as small as that on our standard carbon weave. It is fabricated from 16 gauge wire, midway between our standard carbon and standard sludge weave.

In order to quickly obtain field data on the performance of this new weave, we have utilized it in the latest replacement belt for Passaic unit. Because of schedule considerations, the replacement Passaic belt has been fabricated from available 35% Ni, 19% Cr wire (not Columbium-stabilized). Furthermore, it was not possible to obtain the necessary parts to modify the Passaic unit for the spring-loaded pinch system at the time of installation of the new belt. Therefore, the Passaic unit will provide data as to the relative susceptibility of the new weave over-pinching, as well as its overall performance in the regeneration application. We also intend to evaluate this weave in the sludge incineration application, with the obvious objective of developing a standard belt specification which can be used for a wide range of infrared furnace applications.

We are very confident that the new belt weave, along with the spring loaded pinch adjustment system, will substantially increase the life of the conveyor belt in the infrared furnace and make maintance cost associated with the belt an even smaller fraction of the total carbon regeneration cost. Our field experience to date indicates a substantial increase in the standard carbon belt life with the spring loaded pinch system, and we look forward to the data which will be obtained at Passaic as to the performance of the new belt weave.

Sincerely,

Mac

F.K. McGinnis, III, Ph.D.
Executive Vice President

FKM/lj

cc: Ben Lykins
Jack DeMarco
Wendell Inhoffer (Passaic)

TABLE 1 -

STANDARD INFRARED FURNACE
WOVEN-WIRE CONVEYOR BELT
SPECIFICATIONS

APPLICATION	DESIGNATION	CROSS SECTIONAL AREA (IN^2/FT. WIDTH)	UNIT WEIGHT (LB/FT^2)	THICKNESS (IN)	APPROX. OPENING (IN)
Incineration (Standard)	CB3-30-72-14	0.905	6.0	0.30	0.06
Carbon Regeneration (Standard)	CB5-36-120-18	0.638	3.82	0.20	0.017
Multipurpose (New)	WFC-7 Special	0.900	5.0	0.25	0.020

TABLE 2 -

PASSAIC VALLEY CARBON REGENERATION FURNACE
CONVEYOR BELT HISTORY

DESCRIPTION	WEAVE	ALLOY	DATE INSTALLED	TOTAL OPERATING HOURS (APPROX.)
Original	Standard Carbon	Type 310 SS	11/77	650
First Replacement	Standard Carbon	35-19 CB	12/78	1000
Second Replacement	Multipurpose	35-19	11/79	----

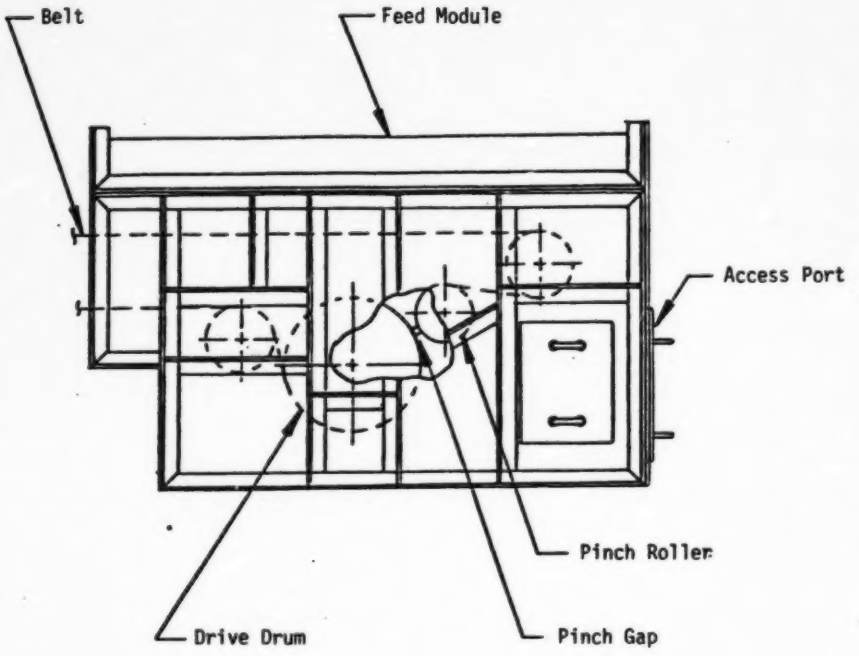

Figure 1

INFRARED FURNACE CONVEYOR BELT DRIVE SYSTEM

APPENDIX C

EXPERIMENTAL ANALYTICAL DATA

TABLE C-1. TOTAL ORGANIC CARBON, VIRGIN CYCLE

Time in Service, weeks	Influent, mg/L	Activated Carbon Effluent, mg/L		
		HD-1030	WV-W	F-400
1	1.75	0.59	0.58	0.67
2	1.48	0.77	0.77	0.81
3	2.08	1.04	1.01	0.89
4	2.58	1.34	1.27	1.23
5	3.02	1.53	1.47	1.32
6	3.82	2.16	2.18	2.27
7	3.34	2.05	2.17	2.04
8	2.72	1.98	1.87	1.82
9	2.29	1.73	1.48	1.46
10	2.55	1.91	1.75	1.62
11	3.14	2.48	2.12	2.17

TABLE C-2. TOTAL ORGANIC CARBON, FIRST REGENERATION

Time in Service, weeks	Influent, mg/L	Activated Carbon Effluent, mg/L		
		HD-1030	WV-W	F-400
1	4.13	2.20	1.50	1.46
2	4.43	2.84	2.14	2.08
3	3.72	2.79	2.00	1.93
4	4.24	3.06	2.63	2.59
5	4.68	3.65	3.15	3.05
6	5.20	3.80	3.42	3.30
7	4.49	3.31	3.27	3.26
8	4.44	3.69	3.32	3.35
9	4.25	3.52	3.27	3.24
10	4.51	3.61	3.45	3.39
11	4.47	3.33	3.38	3.27
12	4.19	3.42	3.33	3.46
13	4.12	3.46	3.24	3.31
14	4.48	3.92	3.77	3.64
15	2.96	2.70	2.71	2.61
16	3.88	3.09	2.77	3.33

TABLE C-3. TOTAL ORGANIC CARBON, SECOND REGENERATION

Time in Service, weeks	Influent, mg/L	Activated Carbon Effluent, mg/L		
		HD-1030	WV-W	F-400
1	2.42	0.26	0.14	0.15
2	2.34	0.65	0.59	0.53
3	2.66	1.20	0.93	0.87
4	3.18	1.37	1.39	1.18
5	2.85	1.60	1.65	1.52
6	2.81	2.02	1.90	1.58
7	2.90	2.04	1.92	1.63
8	3.35	2.15	2.10	1.75
9	3.37	2.40	2.18	1.96
10	3.16	2.10	1.90	1.70
11	3.38	2.16	2.00	1.81
12	3.22	2.12	2.05	1.80
13	3.71	2.56	2.49	2.28
14	3.60	2.60	2.36	2.39
15	4.72	3.05	3.27	3.03
16	4.41	2.90	2.76	2.56
17	3.30	2.40	2.33	2.18
18	4.19	3.21	2.88	2.78
19	3.74	2.93	2.65	2.66

TABLE C-4. TOTAL ORGANIC CARBON, THIRD REGENERATION

Time in Service, weeks	Influent, mg/L	Activated Carbon Effluent, mg/L		
		HD 1030	WV-W	F-400
1	2.67	0.37	0.70	0.49
2	2.86	1.15	1.40	1.04
3	3.27	1.98	2.04	1.65
4	2.19	1.59	1.74	1.41
5	3.60	3.06	2.86	2.49
6	3.07	2.01	1.69	1.67

TABLE C-5. FREE RESIDUAL CHLORINE, VIRGIN CYCLE

Time in Service, weeks	Influent, mg/L	Activated Carbon Effluent, mg/L		
		HD-1030	WV-W	F-400
1	0.83	ND	ND	ND
2	0.78	ND	ND	ND
3	0.95	ND	ND	ND
4	0.90	ND	ND	ND
5	0.95	ND	ND	ND
6	0.80	ND	ND	ND
7	0.70	ND	ND	ND
8	0.95	ND	ND	ND
9	0.94	ND	ND	ND
10	0.68	ND	ND	ND
11	0.85	ND	ND	ND

TABLE C-6. FREE CHLORINE RESIDUAL, FIRST REGENERATION

Time in Service, weeks	Influent, mg/L	Activated Carbon Effluent, mg/L		
		HD-1030	WV-W	F-400
1	1.00	ND	ND	ND
2	0.55	ND	ND	ND
3	0.80	ND	ND	ND
4	0.95	ND	ND	ND
5	0.80	ND	ND	ND
6	1.15	ND	ND	ND
7	0.95	ND	ND	ND
8	1.00	ND	ND	ND
9	1.00	ND	ND	ND
10	0.92	ND	ND	ND
11	1.40	ND	ND	ND
12	1.50	ND	ND	ND
13	1.21	ND	ND	ND
14	1.22	0.32	0.32	0.28
15	1.63	0.35	0.25	0.22
16	1.10	0.30	0.12	0.14

ND = None Detected

TABLE C-7. FREE CHLORINE RESIDUAL, SECOND REGENERATION

Time in Service, weeks	Influent, mg/L	Activated Carbon Effluent, mg/L		
		HD-1030	WV-W	F-400
1	1.10	ND	ND	ND
2	0.95	ND	ND	ND
3	0.70	ND	ND	ND
4	0.90	0.20	0.21	0.21
5	0.75	0.20	0.22	0.18
6	0.85	0.25	0.25	0.20
7	0.70	0.10	0.25	0.10
8	1.00	0.25	0.22	0.11
9	0.60	ND	ND	ND
10	0.75	0.11	0.15	0.19
11	0.70	0.13	0.12	0.14
12	0.70	0.10	0.10	0.14
13	0.70	0.09	0.08	0.18
14	0.85	0.06	0.09	0.10
15	0.80	0.14	0.13	0.12
16	0.90	NA	NA	NA
17	1.00	0.15	0.16	0.20
18	1.05	0.15	0.19	0.16
19	0.85	0.15	0.15	0.16

ND = None detected
NA = Not available

TABLE C-8. FREE CHLORINE RESIDUAL, THIRD REGENERATION

Time in Service, weeks	Influent, mg/L	Activated Carbon Effluent, mg/L		
		HD-1030	WV-W	F-400
1	0.85	0.19	0.11	0.08
2	1.15	0.10	0.11	0.13
3	1.30	0.18	0.19	0.10
4	1.05	0.15	0.29	0.22
5	1.20	0.10	0.21	0.22
6	0.85	0.10	0.11	0.12

TABLE C-9. FLUORESCENCE MEASUREMENTS, VIRGIN CYCLE

Time in Service, weeks	Influent, RFM Units	Activated Carbon Effluent, RFM Units		
		HD-1030	WV-W	F-400
1	14.5	3.5	4.0	4.0
2	11.5	4.0	4.5	4.5
3	14.5	5.5	5.5	4.0
4	15.5	4.5	5.5	4.5
5	17.0	5.5	6.5	4.0
6	22.5	9.0	11.0	10.5
7	18.0	7.0	8.5	7.5
8	15.5	9.0	9.5	8.5
9	17.5	9.5	8.5	7.5
10	19.5	16.0	13.5	10.5
11	27.5	17.0	14.0	14.0

TABLE C-10. FLUORESCENCE MEASUREMENTS, FIRST REGENERATION

Time in Service, weeks	Influent, RFM Units	Activated Carbon Effluent, RFM Units		
		HD-1030	WV-W	F-400
1	35.0	10.5	7.0	6.0
2	39.0	16.0	12.0	11.0
3	29.0	16.0	12.0	11.0
4	35.0	19.0	16.0	13.0
5	29.0	16.0	14.0	13.0
6	32.0	21.0	17.0	14.0
7	25.0	14.5	13.0	12.0
8	25.5	17.0	14.5	14.0
9	22.0	17.0	14.0	14.5
10	31.5	20.0	19.0	17.5
11	26.5	19.0	18.5	16.0
12	23.0	19.0	18.0	17.0
13	30.0	21.0	20.0	20.0
14	25.0	21.0	20.0	19.0
15	17.0	14.0	13.0	13.0
16	20.0	15.0	13.0	15.5

TABLE C-11. FLUORESCENCE MEASUREMENTS, SECOND REGENERATION

Time in Service, weeks	Influent, RFM Units	Activated Carbon Effluent, RFM Units		
		HD-1030	WV-W	F-400
1	12.0	0.5	2.0	0.5
2	13.0	1.5	2.0	1.5
3	12.0	4.5	4.0	2.5
4	19.0	4.0	5.5	4.0
5	16.0	6.5	8.5	6.5
6	19.5	9.5	10.5	7.5
7	20.5	11.0	11.5	9.5
8	23.0	11.0	11.5	8.5
9	23.0	14.0	14.0	11.0
10	16.0	13.5	12.5	10.0
11	18.0	13.0	13.0	10.0
12	14.5	13.0	11.0	9.5
13	14.5	15.0	12.0	11.0
14	17.0	14.5	11.5	10.5
15	25.5	16.5	16.0	14.5
16	18.5	15.5	13.5	11.5
17	13.5	15.0	15.0	12.0
18	16.5	17.0	15.5	12.5
19	14.5	18.5	16.5	11.5

TABLE C-12. FLUORESCENCE MEASUREMENTS, THIRD REGENERATION

Time in Service, weeks	Influent, RFM Units	Activated Carbon Effluent, RFM Units		
		HD-1030	WV-W	F-400
1	12.5	3.0	6.0	3.5
2	12.0	6.5	8.5	7.5
3	10.0	9.0	10.0	5.5
4	21.0	15.5	15.0	12.5
5	14.0	9.0	8.5	7.5
6	14.5	11.5	10.0	9.0

TABLE C-13. HYDRAULIC LOADING* ON THE GRANULAR ACTIVATED CARBON

Time in Service, weeks	Flow Rate, gallons per min (m^3/min)		
	HD-1030	WV-W	F-400
1	480 (1.8)	480 (1.8)	480 (1.8)
2	490 (1.9)	490 (1.9)	490 (1.9)
3	480 (1.8)	480 (1.8)	480 (1.8)
4	490 (1.9)	480 (1.8)	480 (1.8)
5	480 (1.8)	480 (1.8)	480 (1.8)
6	480 (1.8)	480 (1.8)	480 (1.9)
7	490 (1.9)	490 (1.9)	490 (1.9)
8	480 (1.8)	480 (1.8)	480 (1.8)
9	480 (1.8)	480 (1.8)	475 (1.8)
10	490 (1.9)	480 (1.8)	480 (1.8)
11	480 (1.8)	480 (1.8)	480 (1.8)

*This is for virgin cycle but is typical of the near constant flow rates through the entire study.

TABLE C-14. TOTAL ORGANIC HALOGEN ADSORBED DURING VIRGIN CYCLE

Time in Service, weeks	Activated Carbon TOX, mg/g					
	HD-1030		WV-W		F-400	
	Top	Bottom	Top	Bottom	Top	Bottom
1	0.3	0.3	0.1	<0.1	0.1	<0.1
2	0.8	0.6	0.4	0.2	1.2	0.3
3	0.8	0.3	2.1	0.2	1.8	0.2
4	2.0	0.6	1.4	0.2	2.2	0.4
5	2.1	0.8	1.4	0.2	2.4	0.6
6	3.0	0.8	2.3	1.6	3.2	1.4
7	3.2	1.2	2.1	0.9	3.2	1.2
8	3.6	1.2	2.4	1.3	3.4	1.6
9	4.3	1.8	2.3	1.2	3.3	2.0
10	4.6	2.0	2.6	1.6	3.5	2.4
11	4.6	2.0	3.0	1.4	3.8	2.4

TABLE C-15. TOTAL ORGANIC HALOGEN ADSORBED AFTER FIRST REGENERATION

Time in Service, weeks	TOX, mg/g					
	HD-1030		WV-W		F-400	
	Top	Bottom	Top	Bottom	Top	Bottom
1	1.6	1.2	1.6	0.6	2.2	0.8
3	2.0	1.8	1.4	0.8	2.8	1.6
5	2.4	2.1	2.2	1.9	3.3	2.4
7	3.0	2.2	2.3	1.7	3.6	2.3
9	2.5	2.4	2.4	2.2	3.4	2.7
11	3.6	2.3	2.7	2.2	3.6	2.9
13	3.3	2.5	2.9	2.4	3.7	3.1

TABLE C-16. TOTAL ORGANC HALOGEN ADSORBED AFTER SECOND REGENERATION

Time in Service, weeks	TOX, mg/g					
	HD-1030		WV-W		F-400	
	Top	Bottom	Top	Bottom	Top	Bottom
0	2.6	0.4	0.5	0.2	1.6	0.6
1	1.2	0.8	1.4	0.6	1.9	0.8
3	2.5	3.6	2.2	1.2	3.3	1.2
5	3.8	3.6	2.3	2.0	2.5	1.6
7	4.5	2.3	2.1	2.1	2.6	2.1
9	3.4	2.7	2.3	2.1	3.2	2.3
11	3.6	2.7	2.4	2.6	3.1	3.0
13	2.8	-	1.8	2.1	3.0	2.2
15	3.0	2.5	1.8	1.9	-	2.2
17	3.0	2.9	2.0	2.3	2.4	1.6

TABLE C-17. NON-PURGEABLE TOTAL ORGANIC HALOGEN REMOVAL, VIRGIN CYCLE

Time in Service, weeks	Influent, ug/L	Activated Carbon Effluent, ug/L		
		HD-1030	WV-W	F-400
0	87	9	2	23
1	153	46	47	37
2	124	46	50	69
3	150	60	40	30
4	160	70	50	60
5	170	60	60	60
6	320	120	110	90
7	310	150	120	140
8	260	150	120	120
9	190	110	140	140
10	260	170	140	150
11	320	170	160	170
12	310	200	180	190
13	320	170	140	150

TABLE C-18. TOTAL ORGANIC HALOGEN REMOVAL, FIRST REGENERATION

Time in Service, weeks	Influent, ug/L		Activated Carbon Effluent, ug/L					
			HD-1030		WV-W		F-400	
0	149[a]	294[b]	38[a]	44[b]	2[a]	157[b]	8[a]	16[b]
1	106	149	80	273	37	-	55	134
3	182	248	104	154	80	121	74	141
5	209	258	136	180	122	166	87	145
7	255	402	170	246	149	188	129	227
9	261	264	160	173	154	174	149	220
11	195	224	180	207	138	209	125	200
13	-	-	208	284	182	263	147	222
15	151	188	196	266	118	205	99	156
17	170	236	183	238	104	182	77	137

[a]non-purgeable organic halogen as Cl^-
[b]non-purgeable + purgeable organic halogen as Cl^-

TABLE C-19. TOTAL ORGANIC HALOGEN REMOVAL, SECOND REGENERATION

Time in Service, weeks	Influent, ug/L		Activated Carbon Effluent, ug/L					
			HD-1030		WV-W		F-400	
0	122[a]	157[b]	15[a]	15[b]	ND[a]	3[b]	4[a]	4[b]
1	79	149	33	38	18	21	33	38
2	96	135	35	52	31	34	36	51
4	140	203	60	136	70	116	60	130
6	115	229	107	185	85	180	110	151
8	166	197	74	126	76	193	74	153
10	101	182	86	173	62	161	-	-
12	132	243	75	153	83	185	80	110
14	220	457	116	212	91	224	101	190
16	156	198	87	263	79	274	66	125
18	97	137	105	143	84	166	71	162

ND = Not detected
[a]non-purgeable organic halogen as Cl^-
[b]non-purgeable + purgeable organic halogen as Cl^-

TABLE C-20. TYPICAL INFRARED FURNACE LOG SHEET @ START-UP

Elapsed Time, hr	Total Power, kW-hr	Temp, °F		O_2 Feed, %	Belt Width, in	Belt Feed Setting
		Zone A	Zone B			
0.5	20	-	-	-	-	-
1.0	40	-	-	-	-	-
1.5	60	1400	1520	-	-	-
2.0*	70	1500	1700	-	-	
2.5	90	1500	1700	18	15	5
3.0	110	1500	1700	12	22	4.5
3.5	130	1500	1700	13	12	4.5
4.0	150	1500	1700	13	15	4.5
4.5	160	1500	1700	12	15	4.5
5.0	170	1500	1700	12	15	4.5

*begin granular activated carbon feed